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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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LANDING CHARACTERISTICS IN WAVES OF THREE DYNAMIC MODELS OF FLYING BOATS

By James M. Benson, Robert F. Havens, and David R. Woodward

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

Powered models of three different flying boats (one model with unusually long afterbody) were landed in oncoming waves of various heights and lengths. The resulting motions and accelerations were recorded to survey the effects of varying the trim at landing, the deceleration after landing, and the size of the waves.

The data for landings with normal rates of deceleration indicated that the most severe motions and accelerations were likely to occur at some period of the landing run subsequent to the initial impact. Landings made at abnormally low trims led to unusually severe bounces during the landing run. The least severe landings occurred after a stall landing when the model was rapidly decelerated at about 0.4g in a simulation of the proposed use of braking devices. The severity of the landings increased with wave height and was at a maximum when the wave length was of the order of from one and one-half to twice the over-all length of the model.

The models with afterbodies of moderate length frequently bounced clear of the water into a stalled attitude at speeds below flying speed. The model with the long afterbody had less tendency to bounce from the waves and consequently showed less severe accelerations during the landing run than the models with moderate lengths of afterbody.

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[1]Supersedes NACA RM L6L13, "Landing Characteristics in Waves of Three Dynamic Models of Flying Boats" by James M. Benson, Robert F. Havens, and David R. Woodward, 1947.

INTRODUCTION

The development of techniques employing powered models that are dynamically similar to the full-size seaplane has been a significant advancement in tank testing in recent years. The powered models have been used extensively to simulate take-offs and landings for investigating stability and spray characteristics in calm water. The purpose of the present investigation was to survey, by means of corresponding methods, the landing characteristics of three different flying boats in waves. The characteristics of special interest were the vertical and angular motions and accelerations of the airplane that occur during landings in oncoming waves.

Models of three different designs of large flying boats were tested in rough water representing, for the full-size airplanes, waves of various sizes up to about 600 feet in length and 6 feet in height. The types of wave ranged from a short chop to the equivalent of a long ground swell. All landings were made with one-quarter thrust and with the elevator fixed throughout the landing run.

A few preliminary trials indicated that low-trim landings imposed excessive loads and motions on the model. Most of the landings, therefore, were made in a manner that simulated a near-stall landing from a low altitude. The range of sinking speeds during the landing approach corresponded to current practice in piloting.

The scope of the investigation differs from, but is related to, the experimental investigations conducted in the Langley impact basin. The landing tests in the Langley tank no. 1 provide a means of obtaining the vertical and angular motions and accelerations of a complete dynamic model throughout the entire landing run. Study can be made of the conditions leading to or resulting from any impact which is considered critical. The tests in the Langley impact basin have been directed more toward a carefully controlled investigation of pressures and loads encountered during a single impact that may occur at any part of the landing run.

PROBLEM

The requirements for rough-water take-offs and landings are an important part of the design specifications for ocean-going flying boats. The requirements for one proposed design were:

> "For maximum use . . . . .it (the airplane) must be able to operate from forward areas without any more protection than the lee of a small island. . . . . . . and if tactical considerations require open-sea operations, then the airplane must be able to disregard almost any weather."

The problem of designing an airplane capable of fulfilling such requirements has been complicated by the lack of adequate data on the behavior of an airplane in rough water. The parts of the problem that are most adaptable to tank testing are those relating to spray, accelerations, and dynamic stability and control during take-off and landing. The accelerations and the longitudinal dynamic stability while landing in waves were considered to be of immediate interest and are the only phases of the problem included in the present paper.

Specific problems that arose in planning the tests were the choice of piloting technique to be employed, the choice of sea conditions that should be simulated, and the selection of criterions to evaluate the characteristics of a particular design.

In selecting a suitable piloting technique for the models, consideration was given to the results of recent tests which showed that down-swell and along-swell landings were generally less severe than landings into the waves (reference 1). Since the waves appear to have the most severe effect when they are encountered head-on and since it is highly probable that some landings of the airplane will be made into the waves, making test runs of the model in any direction except into the waves was considered unnecessary for the present purpose.

Reference 1 concludes that the most satisfactory landing would consist of the slowest possible approach with the airplane in a stalled attitude. Manipulation of the controls during the landing run, although declared beneficial, was recommended only for pilots skilled in rough-water operation. The average pilot was advised to maintain a nose-high attitude during the landing run. This procedure justified the technique used in the greater part of the present tests, that is, landing at high trims and maintaining the elevators of the model fixed after trimming the model for the initial contact.

In the selection of sizes of waves to be used in the tests, a simple wave pattern that could be consistently reproduced appeared preferable to complex patterns that predominate in the sea. Some of the degenerative characteristics of ocean waves, however, are also to be found in waves in the towing basin. The irregularities in the waves in the tank are particularly noticeable at the shorter wave lengths. The selection of waves for the model tests was consequently

affected by the characteristics of the wave maker and by the characteristics of wave motion in the tank. It appeared best to choose a schedule of settings for the wave maker that would insure easy repetition of a particular wave pattern and to accept the necessary approximations in specifying the height and length of the resulting waves. This approach appeared suitable in view of the statistical aspects both of specifying ocean waves and of predicting the parts of a wave train that are involved in various phases of the landing.

In evaluating the dynamic stability characteristics of a seaplane in rough water, consideration was given to the conventionally used criterions for porpoising and skipping and to the aerodynamic stability during the rebounds from the waves. Preliminary tests of the model and a review of records of flight tests indicated strongly that the violence of the motion of a seaplane in rough water precluded the possibility of establishing trim limits of stability or of defining stable ranges of the center of gravity in the way that is ordinarily applicable for calm water. Waves of the sizes that are of interest produce oscillations in trim and rise that may be sufficiently great to cause the seaplane to bounce clear of the water and descend again at an uncontrolled and dangerous attitude. In three different landings, described in reference 1, damage resulted when the airplane dropped into the water after a bounce. This damage occurred at that stage of the landing run where the airplane did not have sufficient speed for good control.

In the present tests, the effect of the waves on the trim and rise appeared to be of more interest than the usual porpoising, and the test program was planned to provide time histories of the trim and rise during the landing run.

Measurements of vertical accelerations are of first importance in any general investigation of rough-water operation and much information has been obtained in the past from flight tests and from tests in the Langley impact basin. A sustained program has been carried out by the Bureau of Aeronautics to establish structural specifications for vertical accelerations. The need for similar specifications for angular accelerations has been recognized, but sufficient data are not available. In the present tests, vertical accelerations were recorded and angular accelerations were derived from a time history of the trim.

MODELS

Landing tests were made of three models of four-engine flying boats. Langley tank model 206 is the model shown in figure 1. Langley tank model 164J is the model shown in figure 2 and Langley tank model 164L (fig. 3) is the same as model 164J except that the afterbody was modified to increase its length from 3.10 to 5.34 times the beam. Additional details of the model are listed in tables 1 and 2.

APPARATUS

Langley tank no. 1.- Reference 2 describes Langley tank no. 1, and reference 3 describes the type of powered model and towing gear used. A sketch of the model and test apparatus together with a photograph of the model landing in waves is given in figure 4. The water in the tank was about 7 feet deep for the present tests. That depth was selected to allow sufficient immersion of the wave maker for the efficient generation of waves. The landings were made in a section of the tank where the effect of aerodynamic ramming was insignificant.

Wave maker.- The wave maker is a swinging plate hinged at the bottom and driven by a connecting rod at the top of the plate. The to-and-fro motions generate waves that travel from the end of the tank through the test section and into an area where they are dissipated by wave suppressors and a beach. The desired height and length of waves are obtained by a suitable combination of stroke and frequency of the plate. The usual practice is to send out a limited train of waves that will arrive in the test section and be fully developed when a test run is to be made. Between tests, the wave maker is idle to permit dissipation of primary and reflected waves.

The waves in the tank depart from a uniform trochoidal pattern by amounts that depend upon the wave length and the distance from the wave maker. Figure 5 includes faired tracings of typical time histories of the water level for three different wave lengths at a station in the test section of the tank. Figure 6 shows the approximate operating limits of the wave machine at the 7-foot water level. The shorter waves are seen to be less regular than the longer waves. The irregularity necessitates rather arbitrary designations of the height. In specifying the heights of ocean waves, it is convenient to use the maximum height that may be observed in an appreciable interval and to disregard the smaller heights that occur in areas of interference. On that basis, the height of the waves in the cross-hatched area of irregular waves in figure 6 was the maximum height recorded in the train. For example, the height of the wave train in part (a) of figure 5 was designated as 2 inches. The height of waves occurring in the area of regular waves in figure 6, where interference was not predominant, was measured as the average wave height. For example, the height of the wave train of part (b) of figure 5 was designated as 3.5 inches and that of part (c) as 4.75 inches.

Instrumentation.- Figure 4 shows the arrangement of instruments on the model and on the towing gear. An accelerometer was fastened to the staff of the model to measure vertical accelerations. This accelerometer is a variable-inductance unit that is used with alternating-current carrier equipment. The accelerometer has a natural

frequency of about 70 cycles per second and is magnetically damped to about 0.7 of the critical value. Calibration of the accelerometer showed that its response to sinusoidal displacements is almost unaffected by frequency up to about 20 cycles per second. At higher frequencies the recorded peak accelerations were lower than the actual peaks by an amount that increased with frequency. At 50 cycles per second the recorded peak was about 0.8 the applied value. Errors introduced by the carrier and recording apparatus, together with all other errors except that of response time, are believed to be within ±10 percent, ±0.2g (where g is the acceleration due to gravity, 32 ft/sec/sec).

Slide-wire pickups were used to record the trim (angle between base line and horizontal), rise, and fore-and-aft position of the model. Each slide-wire pickup is a part of an electrical bridge circuit which is believed to have the following over-all accuracy:

Trim, degree	±1
Rise, inch	±0.25
Fore-and-aft position, inch	±0.25

Contact with a wave crest was recorded when the water completed an electrical circuit through two metal foils supported on a strut from the towing carriage. All data were recorded on a multielement oscillograph. The error introduced by the recording elements of the oscillograph is negligible.

METHODS

Tests of the model simulated a power-on landing with one-quarter thrust and with the elevator set to obtain a predetermined trim at initial contact with the water. The fore-and-aft freedom of the towing gear allowed the model to check in waves, so that, with a suitable carriage deceleration, the model was almost free of longitudinal restraint during the most severe part of the landing run. For most of the tests, the carriage was decelerated at about 0.1g, which is representative of normal full-size conditions. In a few tests, the carriage was decelerated more rapidly - about 0.4g - to represent a landing with additional braking that could be obtained from water brakes or reversed propellers.

Landings were made at different trims ranging from about 2° up to and including the angle of stall. Preliminary landings at trims below 4° resulted in severe rebounds that appeared to endanger the

models and subsequent landings were generally limited to trims of about 8° and higher.

The following measurements, which are indicated in figure 7, were made from records of the landing runs:

Trim, at first contact with the water
Sinking speed immediately preceding initial impact
The vertical acceleration that occurred on the initial impact
The maximum vertical acceleration, the maximum trim, and the maximum change in trim and rise that occurred at any time during the landing run

Vertical acceleration was assumed to be zero with the model in level flight before landing.

Records from the wave-crest indicator provided a rough basis for correlating the position of the model relative to the surface of the waves. The records of wave crests were also of use as a rough check on the wave conditions that prevailed during each landing.

Maximum positive angular accelerations were obtained for a limited number of landings by graphical differentiation of the trim records. Each of the final values is the average of two or more differentiations. These data are necessarily less accurate than the data on vertical accelerations and are useful only as a basis for qualitative comparisons.

RESULTS

Figure 7 is a copy of a typical record of a landing in waves at a deceleration of about 0.1g and at a landing trim of 6.5°. Of particular significance is the record of vertical accelerations showing that the initial impact (1.4g) was less severe than several of the succeeding ones. The most severe impact (4.0g) occurred after the model had traveled 150 feet (1650 ft, full size). Preceding that impact, the model bounced off the water at a trim near the stall and landed again at a low trim. Figure 8 is a trace of a record of one of four landings that were made in waves at a deceleration of approximately 0.4g. On all four landings the first impact was the most severe of any during the landing run. All other data included in the present paper except those given in figure 8 were obtained with a landing deceleration of 0.1g.

A typical landing is illustrated with sketches in figure 9 to show the approximate position of the model relative to the wave at

various periods during the landing run. The model bounced off the water twice and then received the maximum impact near the ninth wave crest. The trim preceding the severe impact decreased rapidly from above the stall to 7.1° at maximum impact.

The variations of vertical acceleration with landing trim and with sinking speed are shown in figures 10 and 11, respectively. Separate plots are made for the initial impact and the impact that produced maximum vertical acceleration. Figure 12 illustrates by bar charts the statistical aspect of the general problem by showing the number of landings as a function of the vertical acceleration encountered during a series of landings that were made under approximately the same conditions. Measurements of accelerations are arranged in groups separated by increments of 1 g.

Data for landings of Langley tank model 206 are arranged in figure 13 to show the effect of wave length on the maximums that occurred in vertical acceleration, trim, change in trim, and change in vertical position during each landing that was made in two heights of waves. All test points are shown regardless of landing trim.

Figures 14 and 15 include data similar to that in figure 13 on maximum acceleration and maximum trim for Langley tank models 164J and 164L, respectively. The maximum angular accelerations computed from records of landings of models 164J and 164L are given in figure 16. Figure 17 shows the effect of increasing the length of the afterbody of model 164 by a comparison of the upper envelopes of the data of figure 14(b) and figure 15(b).

DISCUSSION

Landing trim.- The results of the tests show that no appreciable effect of landing trim on either the variation of trim during the landing run or the maximum vertical acceleration occurred for all landing trims above 4°. Figure 10 shows approximately the same scatter of data for all landing trims, both for the initial impact and the maximum accelerations. The few landings that were made at an initial trim of 4° or less were considered hazardous, inasmuch as they resulted in a greater variation of trim and more severe impacts than landings at higher trims.

As a rule, the impact that caused the maximum vertical acceleration occurred during the landing run after several impacts had been made with

the water. (See fig. 9.) The results of the tests also show that models 206 and 164J often attained a stalled attitude after bouncing clear of the water at speeds below the stall. Frequently the most severe impacts followed large rebounds from the water. (See fig. 9.) These results generally agree with the conditions described in reference 1.

For landings in waves shorter than 1 model length, a limited range of landing trims was determined (4° to 8°) within which landings could be made with considerably less change in trim during the first part of the run than for landings at trims above 8°. For landings within this range of trim, the models contacted approximately six wave crests with only a small change in trim and then proceeded to follow the general pattern obtained for landings at trims above 8°. Inasmuch as the maximum acceleration usually occurred at a point in the landing run where this general trim pattern was being followed, the effect of landing trim on maximum acceleration was negligible for waves shorter than 1 model length.

The results of tests of a $\frac{1}{30}$-size model of a flying boat in waves having a length equal to 1 model length or less are included in reference 4. Those results indicate that the landings with a minimum variation in trim were obtained at an approach trim of 5°. The value of 5° lies within the range of approach trim (4° to 8°) which was found in the present tests to give the least variation of trim in waves of comparable size during landings. Values of the maximum impact loads obtained in the present tests and those of reference 4 are not directly comparable because of differences in the models and in testing techniques.

Sinking speed.- The apparently random variation of vertical acceleration with sinking speed, shown in figure 11, illustrates the strong influence of other variables besides sinking speed in determining the maximum vertical acceleration that will occur upon contact with the water. The results show that a sinking speed as low as 0.5 feet per second (1.2 fps, full size) gave the same value of maximum vertical acceleration as a sinking speed of 4.5 feet per second (10.6 fps, full size). A detailed investigation of any one impact should, of course, take into account the trim, the flight-path angle of the seaplane, and the wave profile, but in the present investigation of entire landing runs all these variables could not be controlled or measured with sufficient accuracy to allow quantitative comparison with theories of impact.

Statistical aspects.- The conditions for the first impact of a landing run are more under the control of the pilot than those of subsequent impacts. The severity of the subsequent impacts is not predictable except as a probability.

In tests of Langley tank model 206 a large number of landings were made for one landing condition to estimate the number of landings that should be made to insure that an impact near the maximum severity would be obtained. That number cannot be precisely defined but an approximate value is obtainable from figure 12(f) where data are shown for as many as 27 landings in waves 4.4 inches high by 15 feet long. One of the landings resulted in a peak of 6.8g and 6 landings resulted in a peak of 5.5g. The lowest peak recorded in the 27 landings was about 2.5g. For the present survey of the problem, ten landing runs in one type of wave appeared to give an adequate distribution. For tests that included a systematic series of different lengths and heights, four landing runs in one particular configuration of waves appeared to provide sufficient data to establish definite trends if the scatter between the values of maximum acceleration obtained was not wide. For example, the vertical accelerations plotted in figure 13 show unmistakable trends that depend upon the total number of test points rather than upon the more limited numbers for any one wave length.

Wave size.- The data presented in figures 13 to 16 show that the maximum accelerations, both vertical and angular, increased with wave height. The maximum trim increased only slightly with wave height. Maximum vertical and angular acceleration, maximum trim, and maximum change in trim and rise attained the greatest values at wave lengths from 15 to 20 feet or wave lengths of the order of from one and one-half to twice the over-all length of the model.

This effect of wave length is to be expected from consideration of the influence of glide path and wave slope on an individual impact. For a given trim and glide path, the impact is greater for the greater wave slope provided the wave is sufficiently long to permit the seaplane to land on the upsloping face of one wave without simultaneous disturbance from neighboring waves. Although consideration of the irregular characteristics of the waves having a length equal to 1 hull length or less precludes an exact comparison of data obtained from tests in short waves with data from tests in longer waves, the shorter waves appear to afford the afterbody a greater opportunity to contact the water and to limit the trim and height of bounce. Such a limitation on the violence of bouncing is instrumental in producing smaller maximum vertical accelerations.

Rate of deceleration.- The rate of deceleration after landing affects the number and height of bounces and thereby influences the probability that, during the landing run, the seaplane will receive an impact which is more severe than the initial impact. This influence is shown by comparing figure 7 which is a record of a landing with 0.1g deceleration and figure 8 which is a record of a landing with a rapid deceleration of 0.4g, such as might be obtained with a braking device. The rapid loss of speed with the fast deceleration prevented any appreciable bouncing. With this limitation on bouncing, no vertical acceleration occurred during the landing run which was greater than the acceleration at initial impact. The values of the vertical accelerations at initial impact for landings at the fast deceleration were higher than the accelerations at initial impact for landings at 0.1g and only slightly lower than the maximum vertical accelerations for landings at 0.1g.

Length of afterbody.- The two models with moderate lengths of afterbody, models 164J and 206, had about the same landing characteristics. The model with the extremely long afterbody, model 164L, however, had significantly lower maximum trims and vertical accelerations than did models 164J and 206. The effect of length of afterbody on maximum vertical acceleration and maximum trim is shown in figure 17. A comparison of figures 16(a) and 16(b) indicates that the maximum angular accelerations obtained with the long afterbody were less than those obtained with the moderate afterbody. One evident reason for the desirable effects of the long afterbody is the pitching restraint imposed by the increased moment arm of the planing area near the sternpost. Observations of the models showed clearly the influence of this restraint in limiting the maximum trim and thereby the height of the bouncing that occurred during the landing run.

CONCLUSIONS

The following conclusions can be drawn from the results of tests of three powered dynamic models landed with fixed elevators in oncoming waves:

1. Landing trim can be considered to have no appreciable influence on the maximum vertical acceleration or variation of trim during landing, except at trims below 4°. Landings at trims below 4° led to unusually severe bounces. In waves shorter than 1 model length, the variation of trim was comparatively small during the first part of the landing run after landings at trims in the range from 4° to 8°.

2. The maximum vertical acceleration for a given wave condition will usually occur during some impact subsequent to the initial impact.

3. The severity of the rough-water landing increases with wave height and is a function of wave length. The most severe landings for all wave heights tested occurred at wave lengths within the range from 15 to 20 feet or from one and one-half to twice the over-all length of the model.

4. Two models with afterbodies of a length typical of current design frequently attained a stalled attitude after bouncing clear of the water at speeds below the stall. The highest trims were attained in waves having a length of from 15 to 20 feet (about 180 to 240 ft, full size).

5. An increase in the length of the afterbody of a model from 3.1 beams to 5.34 beams reduced the magnitude of the maximum vertical acceleration to a great extent and the maximum angular acceleration to a lesser extent in all wave sizes used for the tests. The maximum trims of the model with the long afterbody were consistently lower throughout the landing run.

6. With an increase in the landing deceleration from 0.1g to 0.4g, a value which might be obtainable through the use of a "water brake" or reversed-pitch propellers, the rapid loss of speed prevented any appreciable bouncing and no vertical acceleration occurred during the landing run which was greater than the acceleration at initial impact. The maximum vertical accelerations were of the same magnitude for landings with decelerations of 0.1g and 0.4g but occurred at different periods of the landing run.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., May 7, 1947

REFERENCES

1. Anon.: Open Sea Seaplane Operations. Rescue Advisory Memo. No. 066, Air Sea Rescue Agency (Washington), 1945.

2. Truscott, Starr: The Enlarged N.A.C.A. Tank, and Some of Its Work. NACA TM 918, 1939.

3. Parkinson, John B., and Olson, Roland E.: Tank Tests of a 1/5 Full-Size Dynamically Similar Model of the Army OA-9 Amphibian with Motor-Driven Propellers – NACA Model 117. NACA ARR, Dec. 1941.

4. Pierson, J.D.: JRM-1 - Landing Impact Characteristics from Model Tests. NACA ARR 5L03, 1946.

TABLE 1

DIMENSIONS AND PARTICULARS OF LANGLEY TANK MODEL 206

Hull:	
Beam at chine at step, in.	14.74
Maximum beam at chine, in.	15.56
Length of forebody (bow to centroid of step), in.	55.75
Length of afterbody (centroid of step to stern post), in.	47.55
Length, over-all, in.	125.21
Plan form of step	45° vee
Point of step to centroid, in.	4.91
Depth of step at keel, in.	1.23
Depth of step at centroid, in.	1.33
Angle of dead rise of forebody (excluding chine flare), deg	25
Angle of dead rise of afterbody at step (excluding chine flare), deg	(approx.)31
Angle of forebody keel, deg	0
Angle of afterbody keel, deg	8.3
Wing:	
Area, sq ft	21.70
Span, in.	175.70
Root chord, in.	26.62
Tip chord, in.	8.82
Root section	NACA 4420
Tip section	NACA 4412
Angle of incidence of root chord, deg	4.5
Angle of incidence of tip chord, deg	1.2
Leading-edge root chord to keel, in.	17.18
Trailing-edge root chord to keel, in.	15.09
Mean aerodynamic chord:	
Length, in.	19.03
Leading edge to leading edge of wing, in.	2.60
Leading edge aft of bow, in.	46.54
Leading edge forward of point of step, in.	14.12

TABLE 1 - Concluded

DIMENSIONS AND PARTICULARS OF LANGLEY TANK MODEL 206 - Concluded

Tail surfaces:	
Horizontal	
Area, sq ft	4.36
Span, in.	46.96
Root chord, in.	14.91
Tip chord, in.	7.45
Root section	NACA 0012
Tip section	NACA 0010
Root incidence to wing root chord, deg	-9.5
Vertical	
Area, sq ft	2.79
Root chord, in.	25.44
Root section	NACA 0012
Tip section	NACA 0012
Height (root to tip), in.	25.91
Propellers:	
Number	4
Blades	4
Diameter, in.	16.64
Blade angle at 0.75 radius, deg	16
Angle of thrust line to base line, deg	4.5
Loading conditions:	
Normal gross load, lb	78.1
Center of gravity:	
Forward step centroid (0.30 M.A.C.), in.	3.5
Above base line, in.	12.0
Pitching moment of inertia, slug-ft^2	8.51

TABLE 2

PRINCIPAL DIMENSIONS OF LANGLEY TANK MODEL 164J

AND CORRESPONDING FULL-SIZE DIMENSIONS

	Model	Full size
Hull:		
Beam, maximum, in.	13.50	162
Length of forebody, in.	48.16	578
Length of afterbody, in.	41.87	502.5
Length of tail extension, in.	30.29	363.5
Length, over-all, in.	120.32	1444
Depth of step at keel, in.	0.62	7.5
Angle of forebody keel, deg	2.0	2.0
Angle of afterbody keel, deg	5.0	5.0
Angle between keels, deg	7.0	7.0
Angle of dead rise at step, deg:		
Excluding chine flare	20.0	20.0
Including chine flare	14.7	14.7
Wing:		
Area, sq ft	25.58	3683
Span, in.	200.0	2400
Root chord (section NACA 23020), ft	2.33	28.0
Tip chord (section NACA 23012), ft	0.78	9.3
Angle of wing setting to base line, deg.	5.5	5.5
Mean aerodynamic chord, in.	20.12	241.4
Leading-edge M.A.C.:		
Aft of bow, in.	37.98	455.7
Above base line, in.	20.22	242.6
Horizontal tail surfaces:		
Span, in.	61.67	740
Leading edge at root:		
Aft of bow, in.	102.2	1225
Above base line, in.	25.0	300
Area, stabilizer, sq ft	3.04	438.4
Area, elevator, sq ft	2.77	384.6
Total area, sq ft	5.71	823.00
Angle of stabilizer to base line, deg	3.0	3.0
Dihedral, deg	8.0	8.0

TABLE 2 - Concluded

PRINCIPAL DIMENSIONS OF LANGLEY TANK MODEL 164J

AND CORRESPONDING FULL-SIZE DIMENSIONS - Concluded

	Model	Full size
Propellers:		
Number	4	4
Blades	3	4
Diameter, in.	16.67	200
Blade angle, deg	13	
Idling speed, rpm	1000	
Full power, rpm	4000	
Angle of thrust line to base line, deg	5.5	5.5
Center line, inboard propellers, above base line, in.	21.2	254.5
Loading conditions:		
Normal gross load, lb	82.5	145,000
Center of gravity:		
Forward step (32 percent M.A.C.), in.	3.74	45
Above base line, in.	[a]14.75	162
Pitching moment of inertia, slug-ft^2	7.8	1,500,000

[a]Center of gravity was raised 1.25 inches so that model could be balanced.

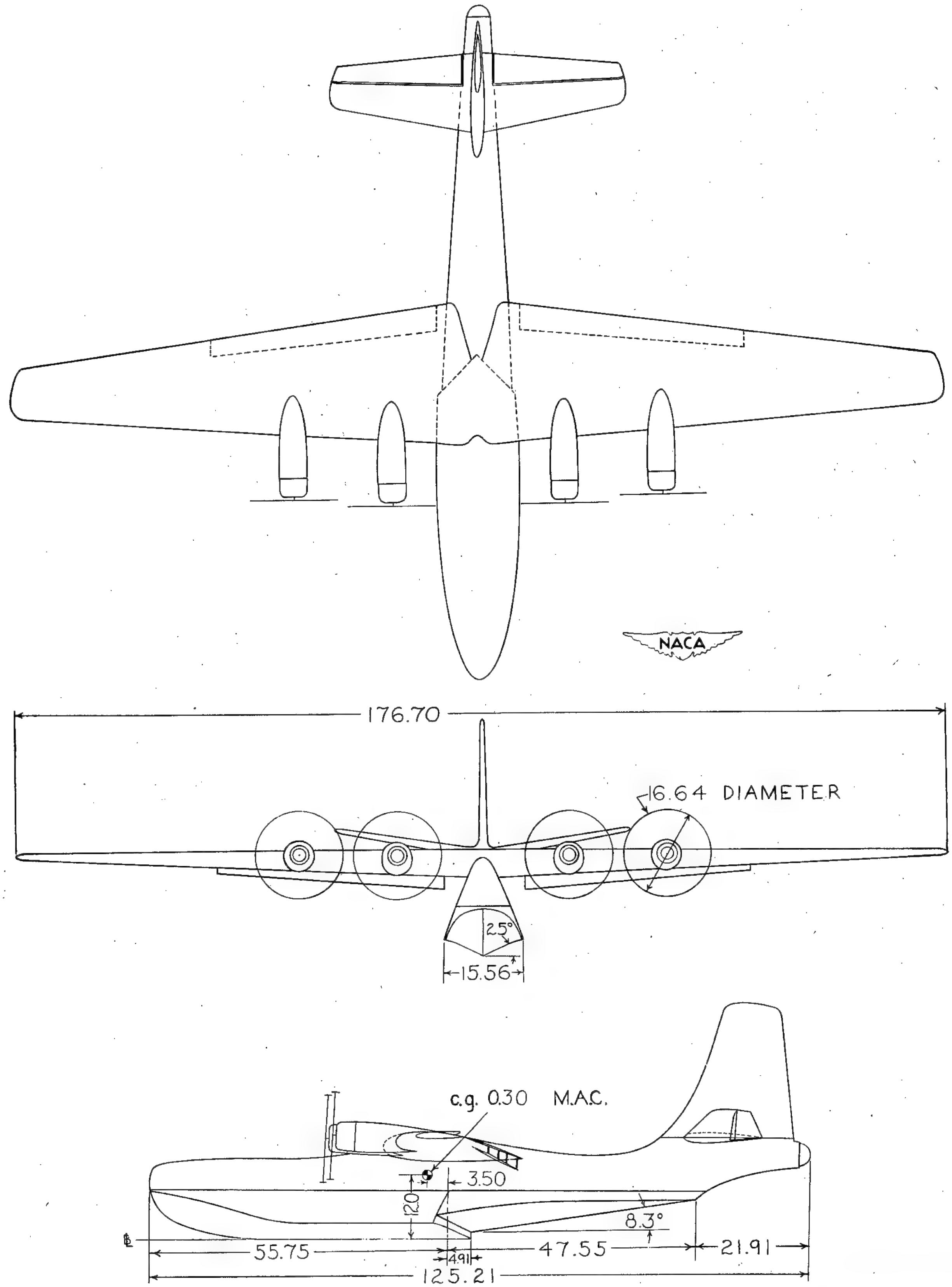


Figure 1.- General arrangement of Langley tank model 206. (All dimensions are in inches.)

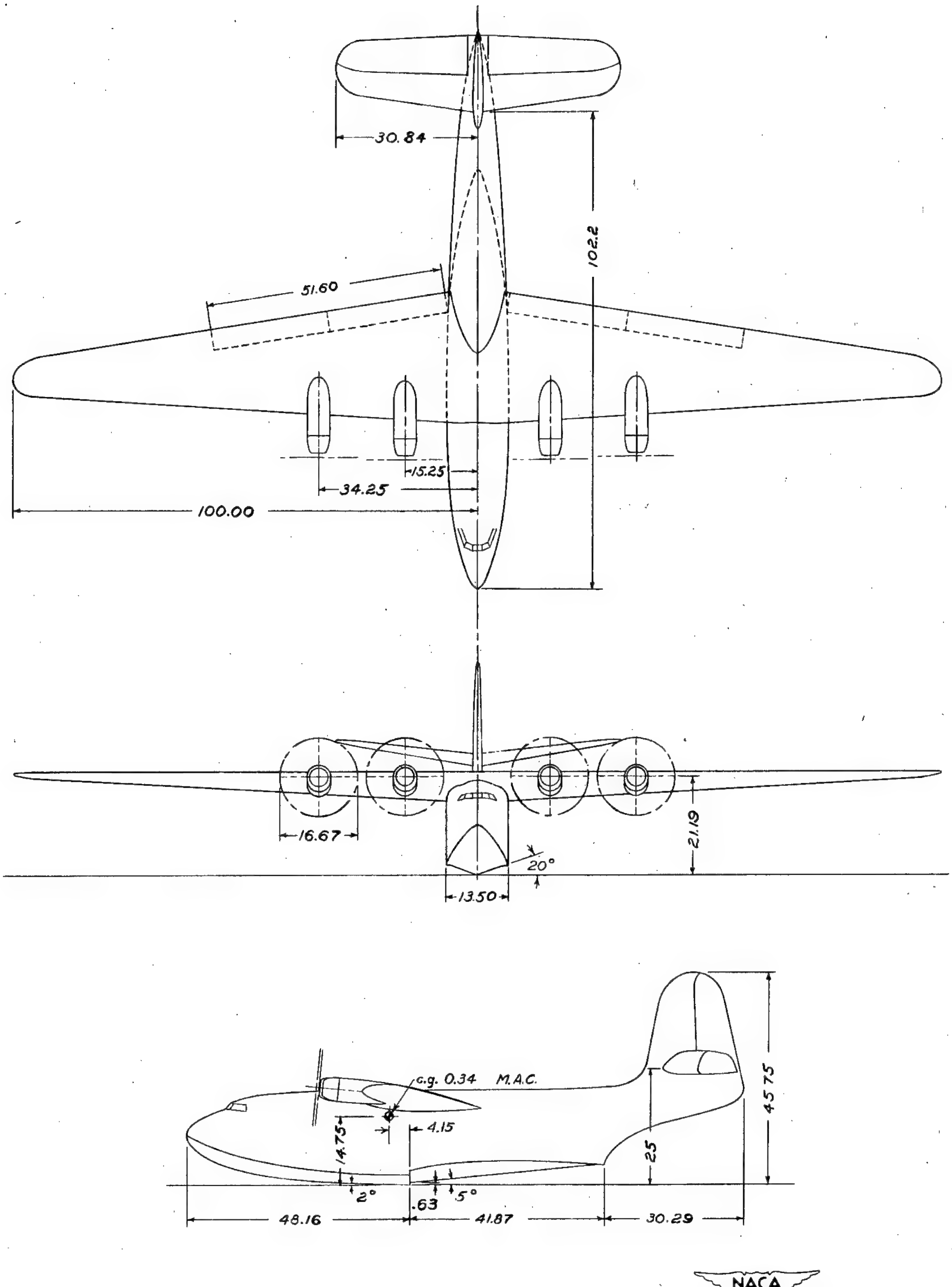


Figure 2.- General arrangement of Langley tank model 164J. (All dimensions are in inches.)

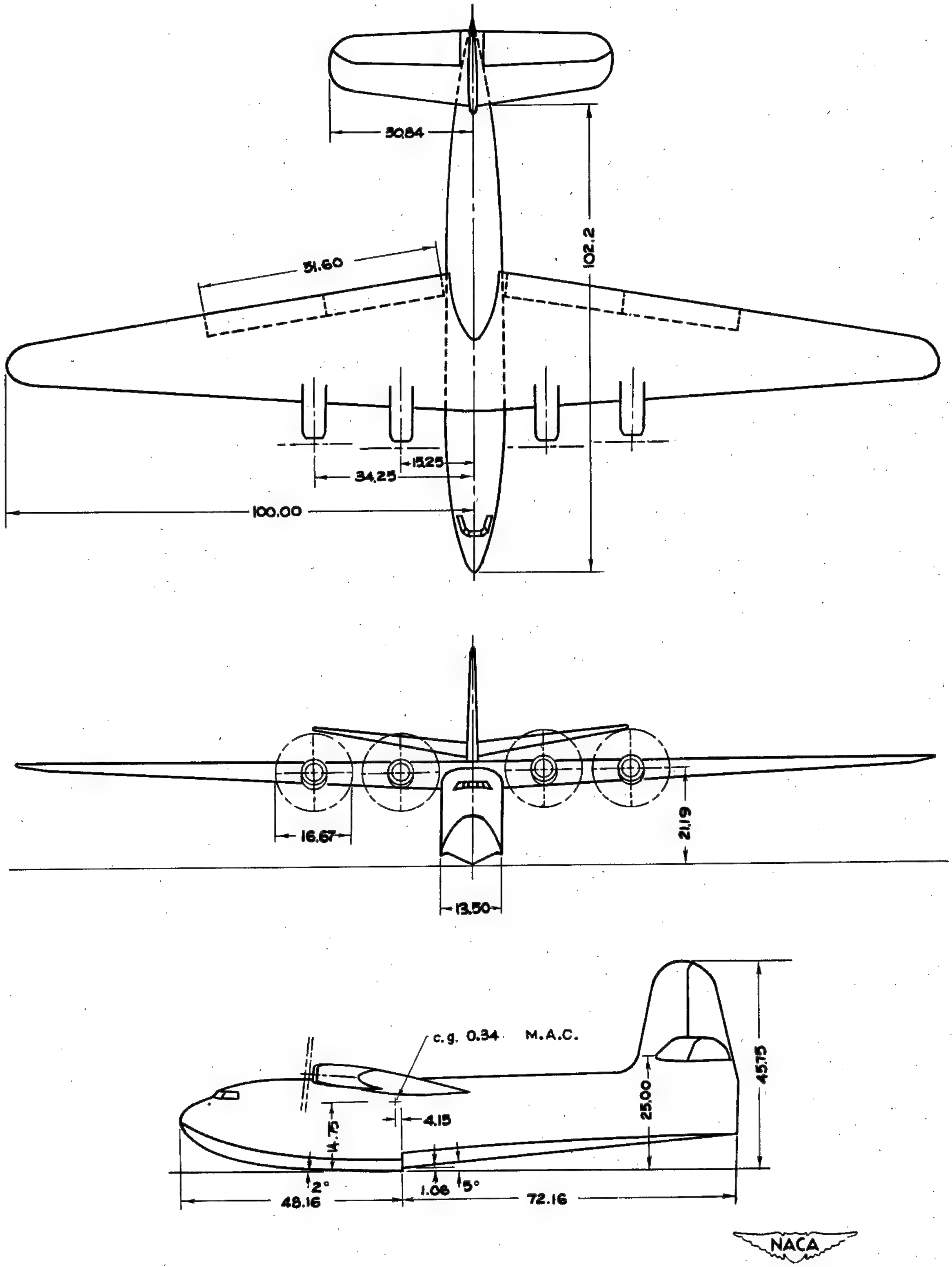
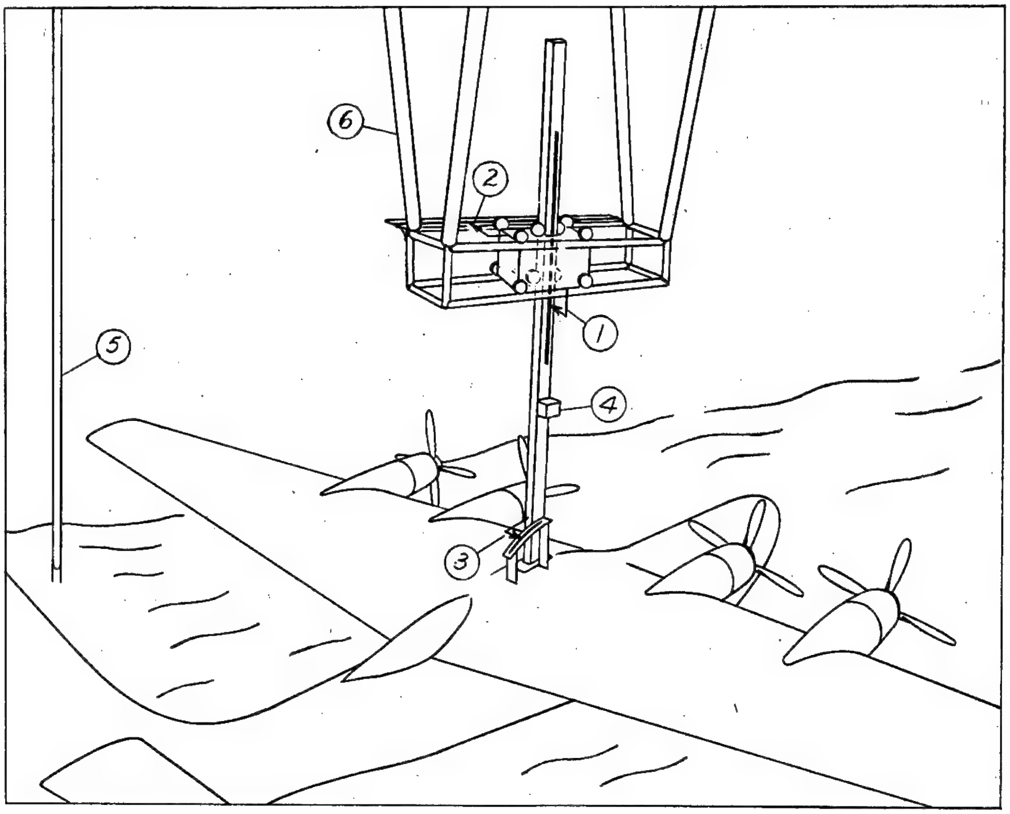
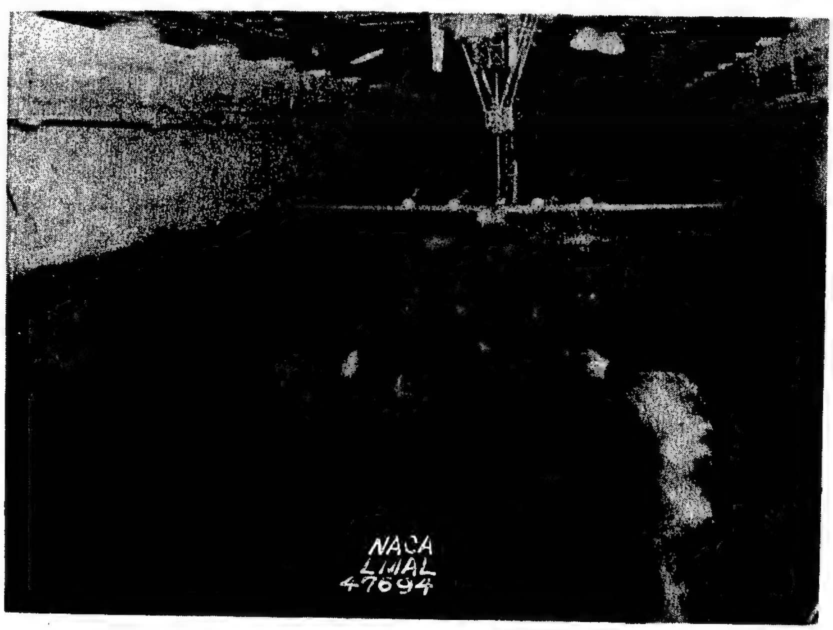


Figure 3.- General arrangement of Langley tank model 164L. (All dimensions are in inches.)

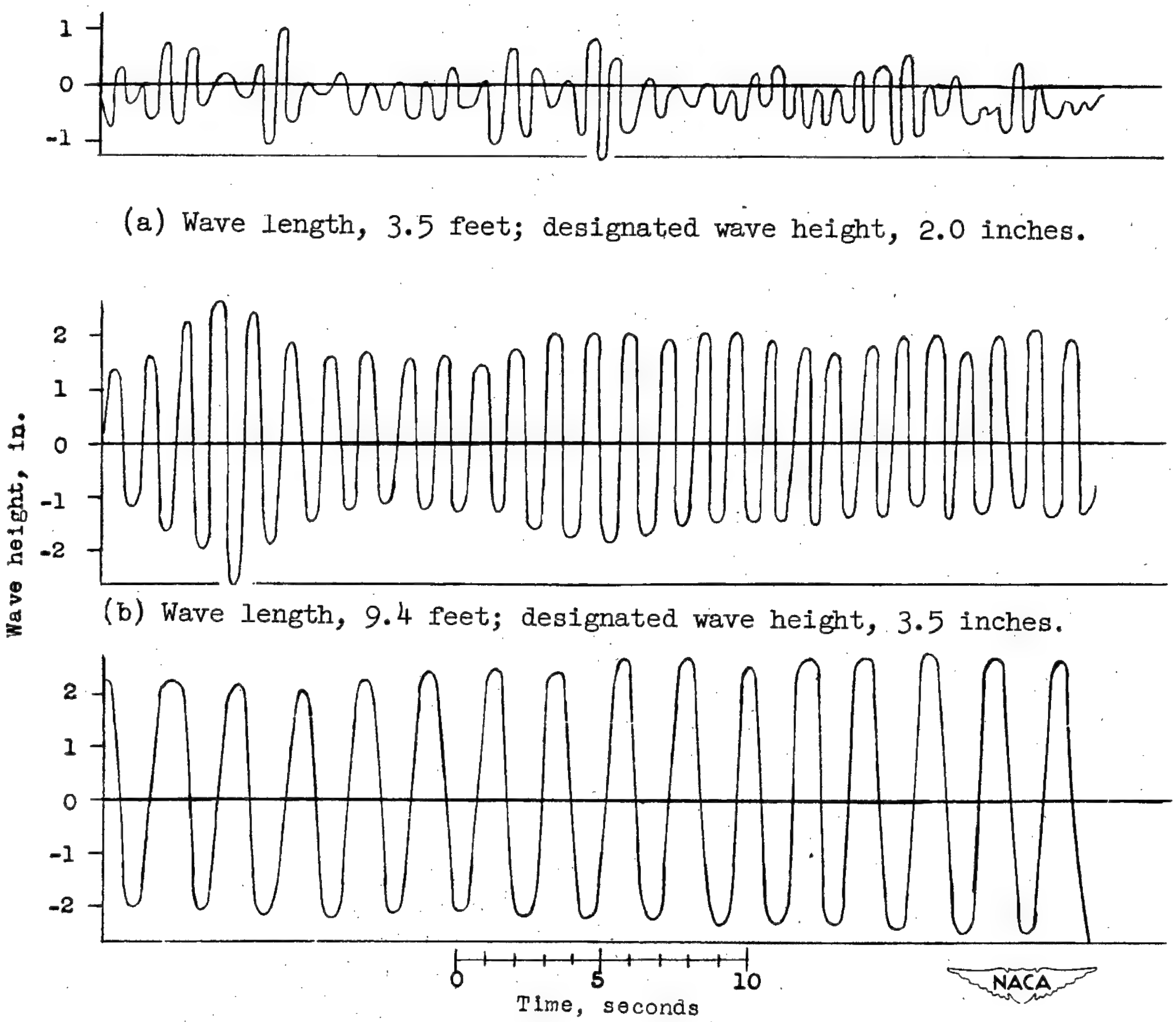


(a) Model and test apparatus. 1 - rise indicator; 2 - fore-and-aft indicator; 3 - trim indicator; 4 - vertical accelerometer; 5 - wave-crest indicator; 6 - towing gear.



(b) Model landing in waves.

Figure 4.- Langley tank model 206 on towing carriage.



(a) Wave length, 3.5 feet; designated wave height, 2.0 inches.

(b) Wave length, 9.4 feet; designated wave height, 3.5 inches.

(c) Wave length, 24.0 feet; designated wave height, 4.75 inches.

Figure 5.- Faired tracings of typical wave records showing variation of height in three different wave trains.

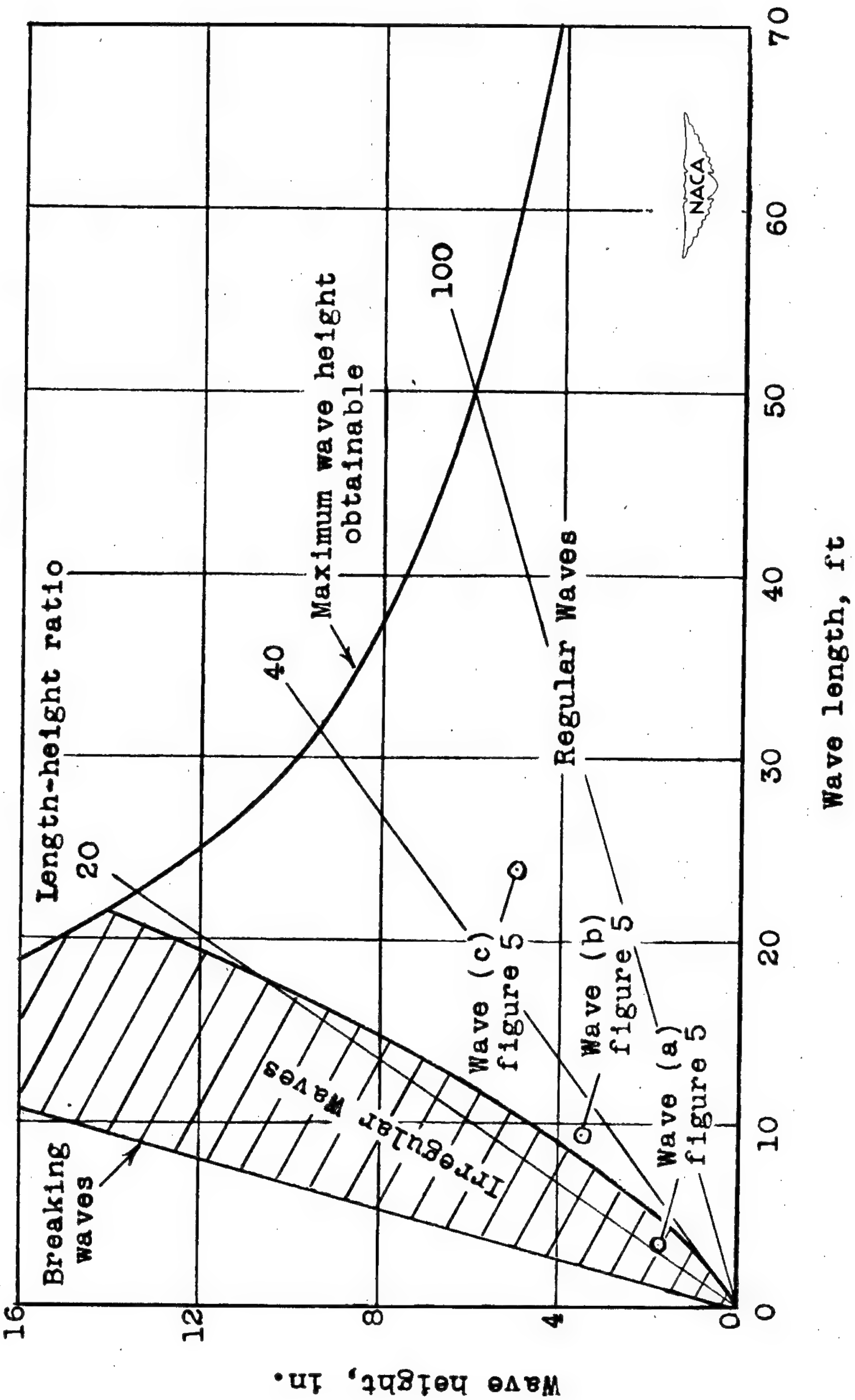


Figure 6.- Approximate operating limits of wave machine at 7-foot water level.

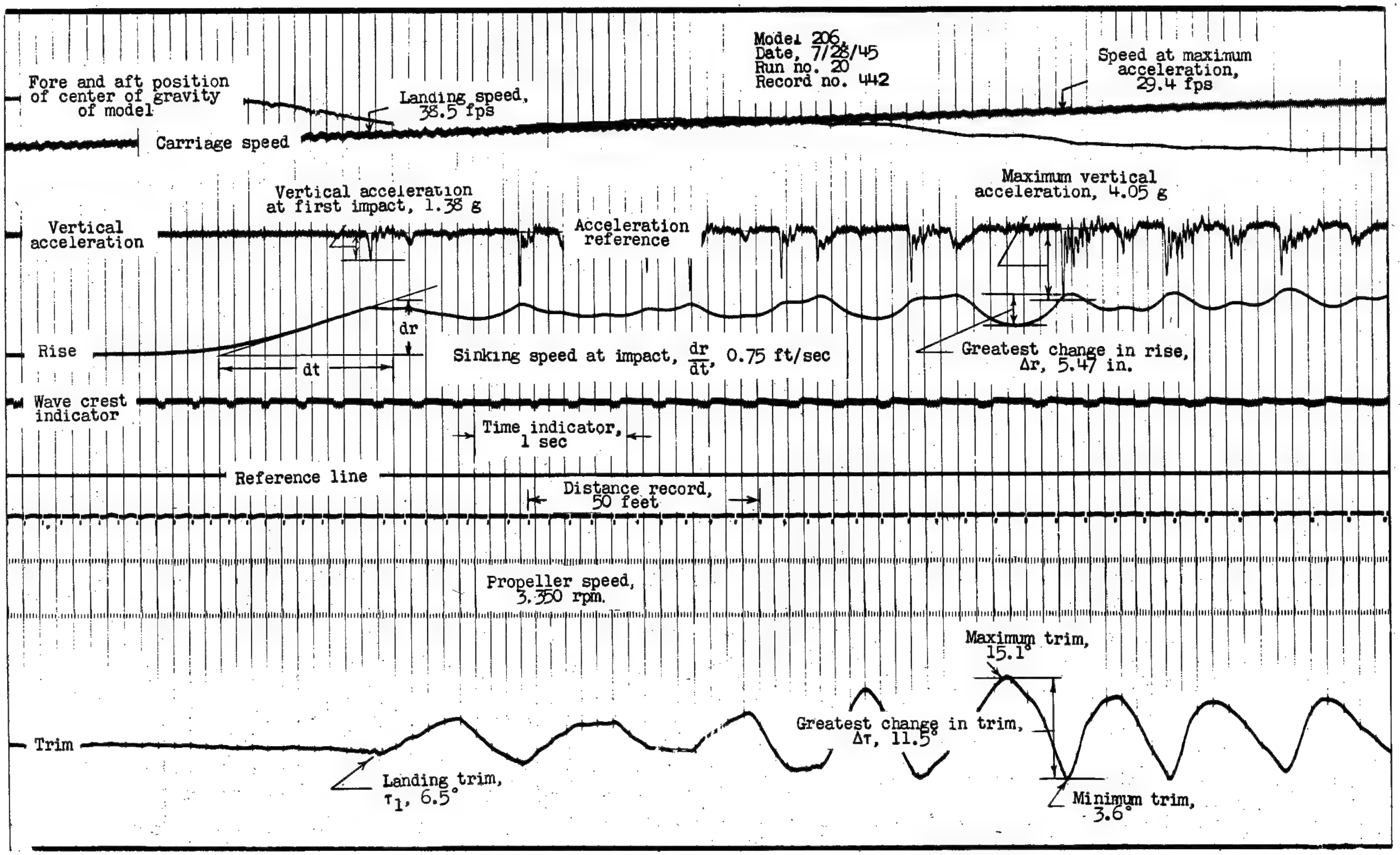


Figure 7.- Langley tank model 206. Photograph of a typical record made while landing in rough water with a deceleration of about 0.1g. Gross load, 78.1 pounds (105,000 pounds, full size); wave, 4.4 inches high and 11 feet long (4 feet high and 121 feet long, full size).

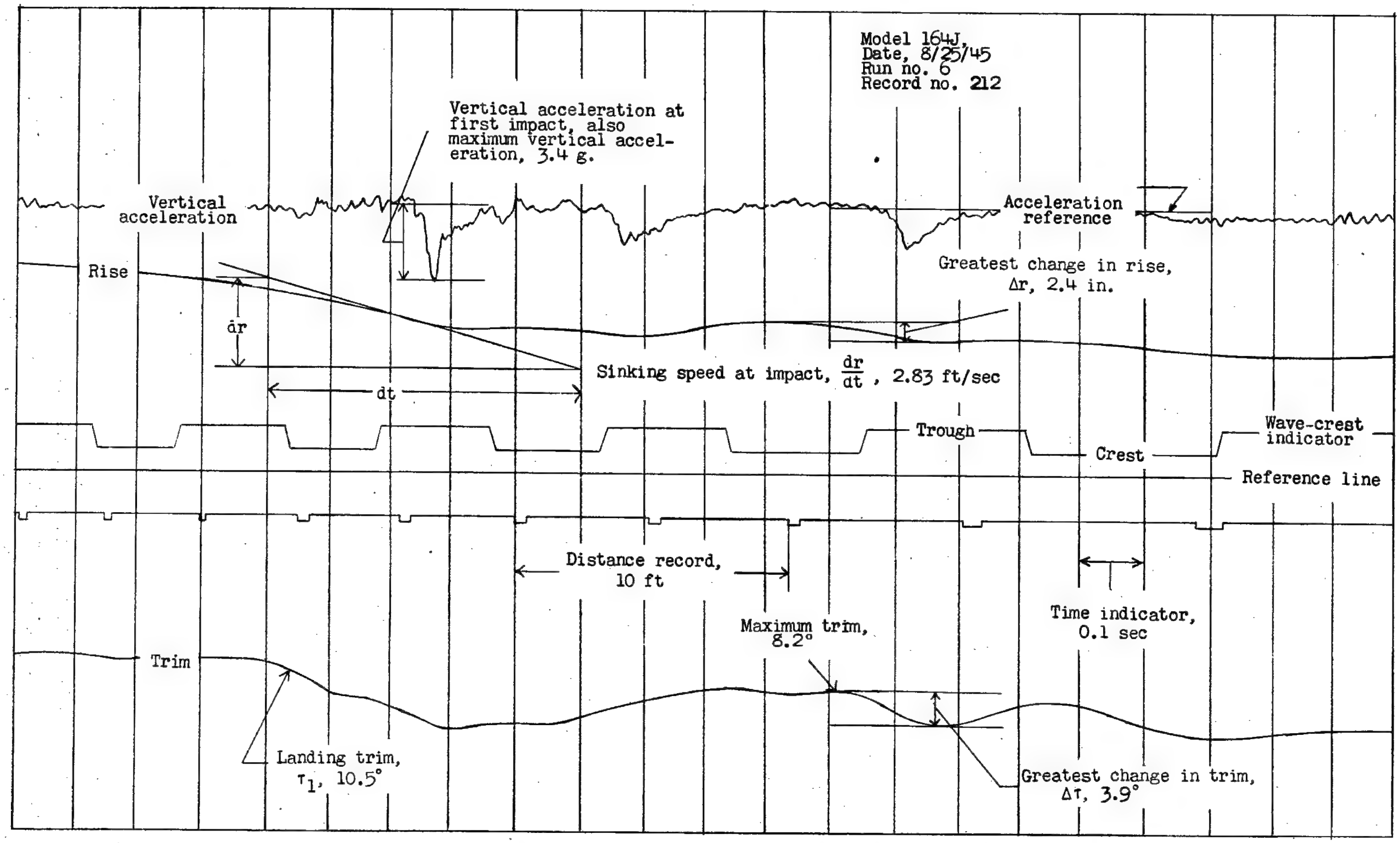


Figure 8.- Langley tank model 164J. Tracing of a typical record taken while landing in rough water at a rate of deceleration of approximately 0.4g. Gross load, 93.9 pounds (165,000 pounds, full size); wave, 4.4 inches high and 11 feet long (4.4 feet high and 132 feet long, full size); approximate deceleration, 13 feet per second per second.

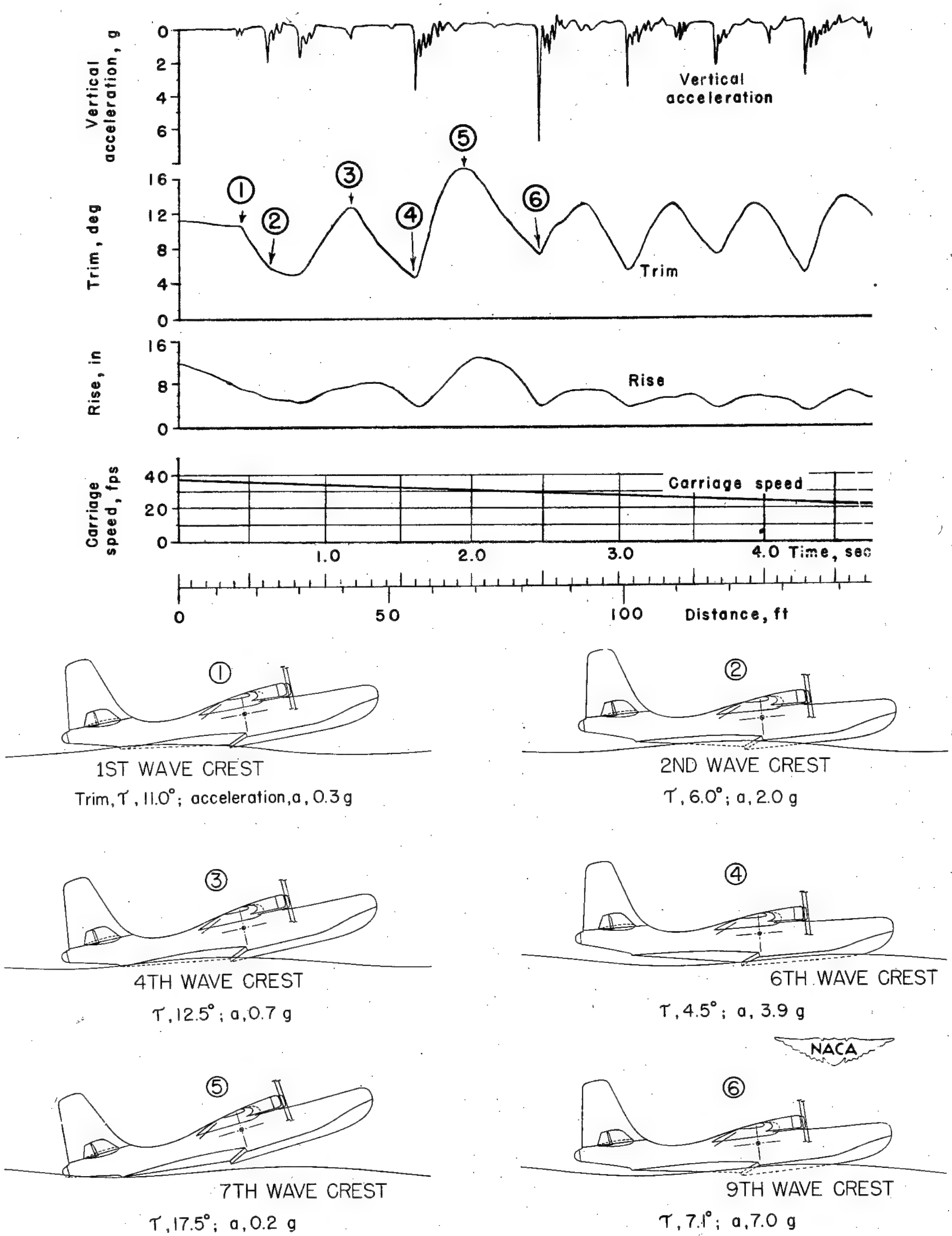
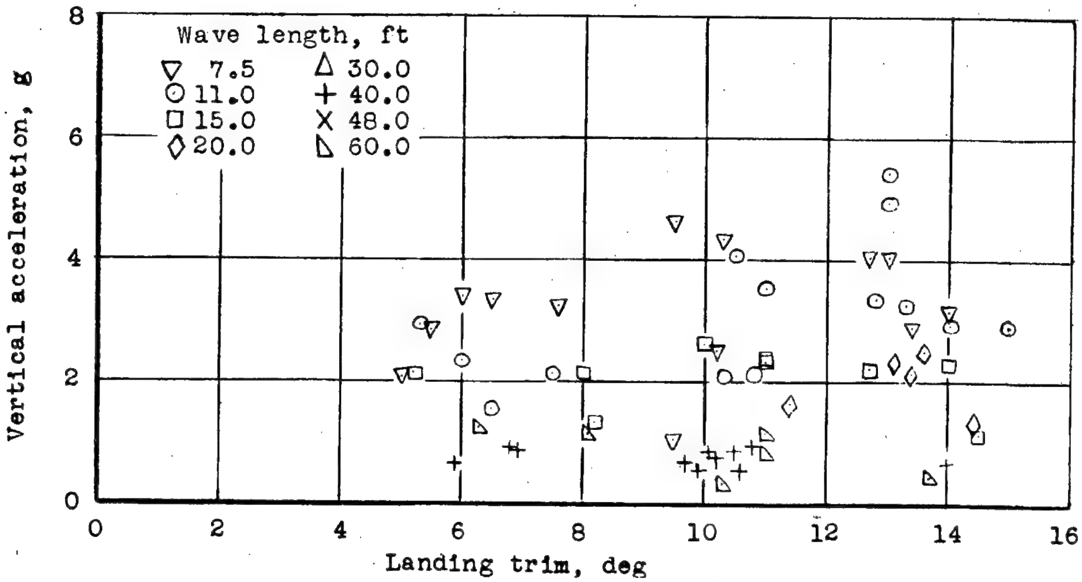
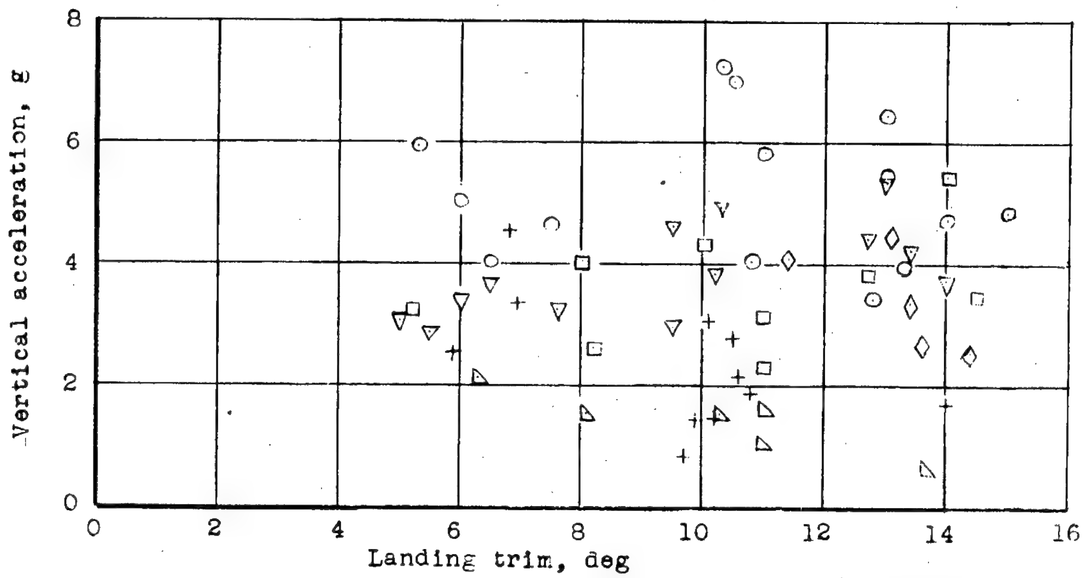


Figure 9.- Langley tank model 206. Time histories of acceleration, trim, rise, and speed during a landing run. (Numbers above illustrations of models refer to points noted on graph of trim.)

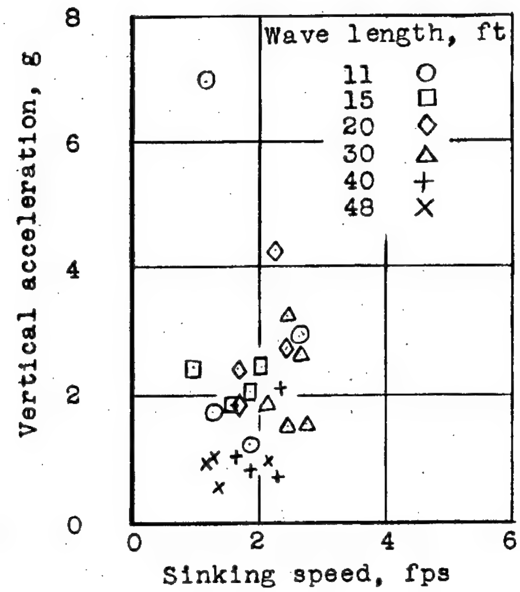


(a) Acceleration at initial impact.

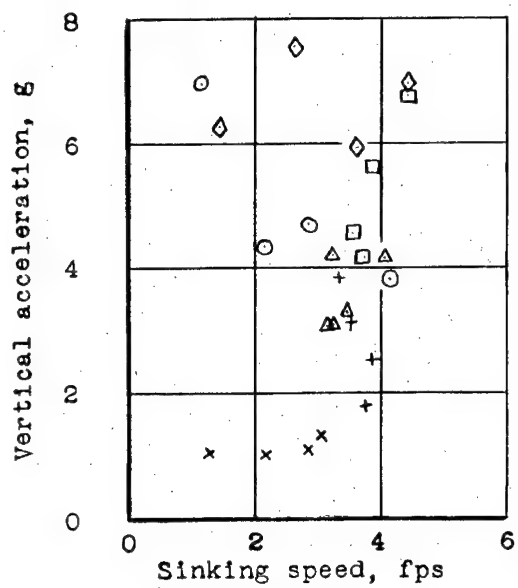


(b) Maximum acceleration that occurred during landing run.

Figure 10.- Langley tank model 206. Variation of vertical acceleration with landing trim during landings in waves 4.4 inches high (4.0 feet, full size).

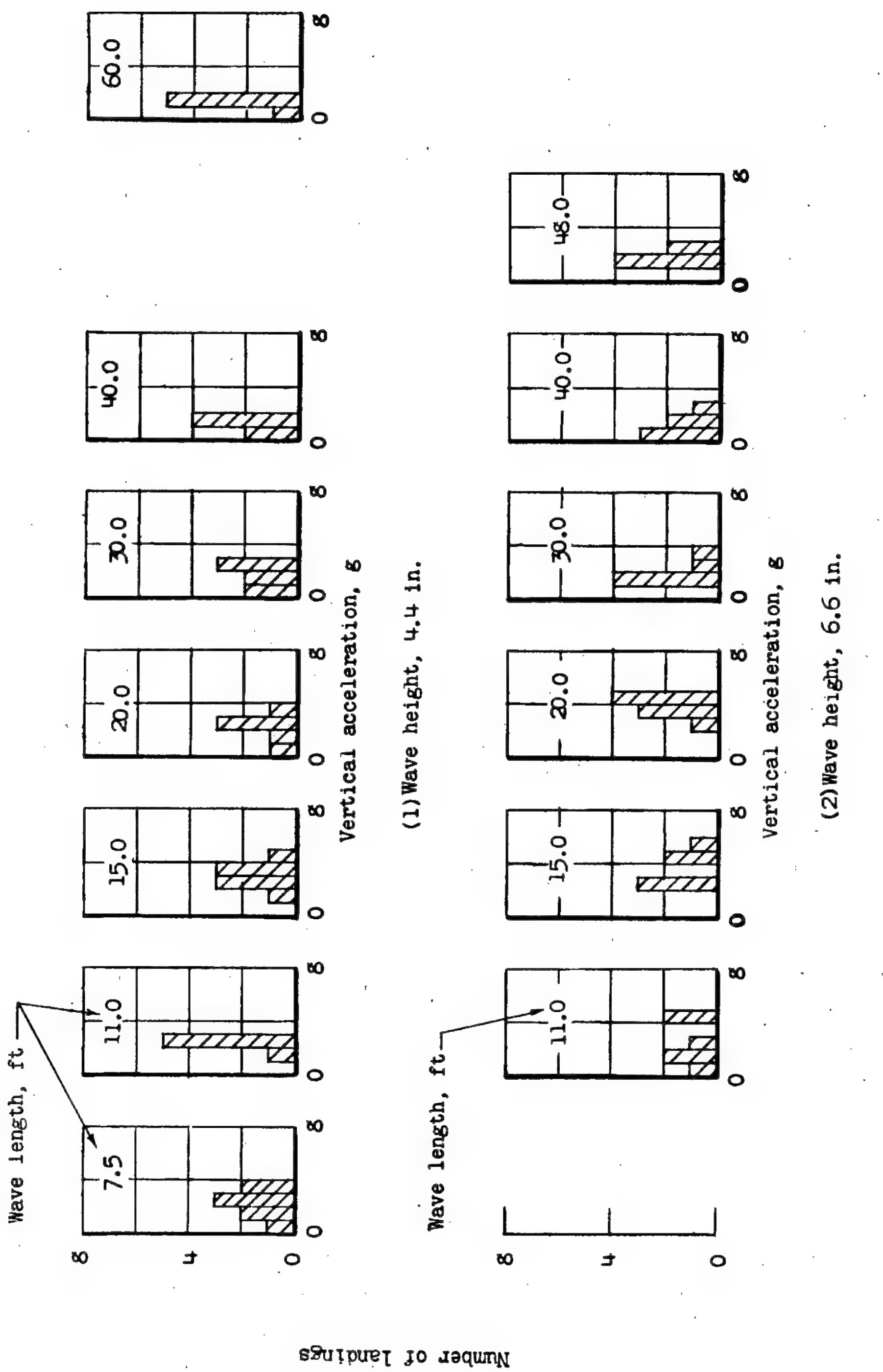


(a) Acceleration at initial impact.



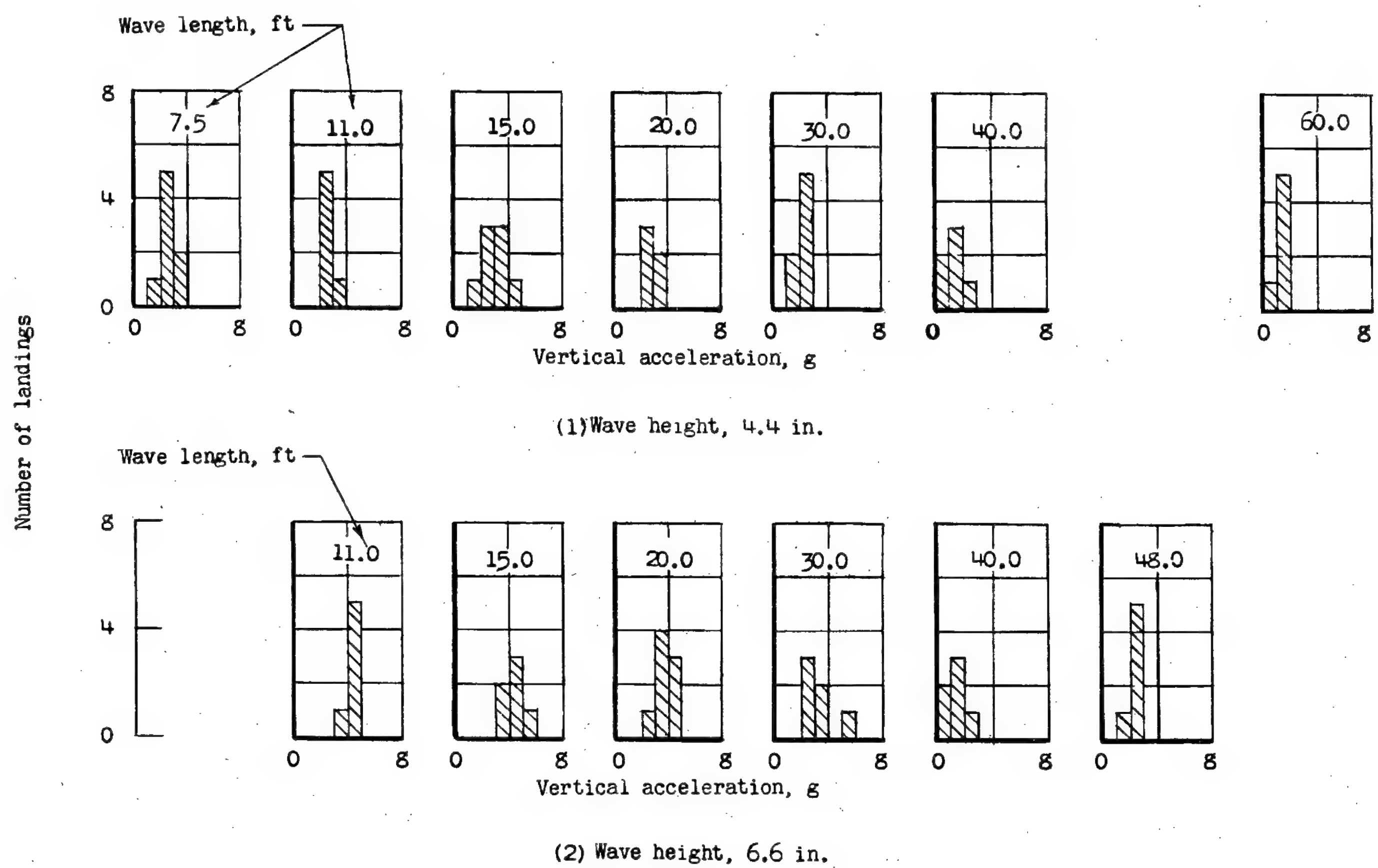
(b) Maximum acceleration that occurred during landing run.

Figure 11.- Langley tank model 164J. Variation of vertical acceleration with sinking speed during landings in waves 6.6 inches high (6.6 feet, full size). (The sinking speed is that speed preceding contact with the water.)



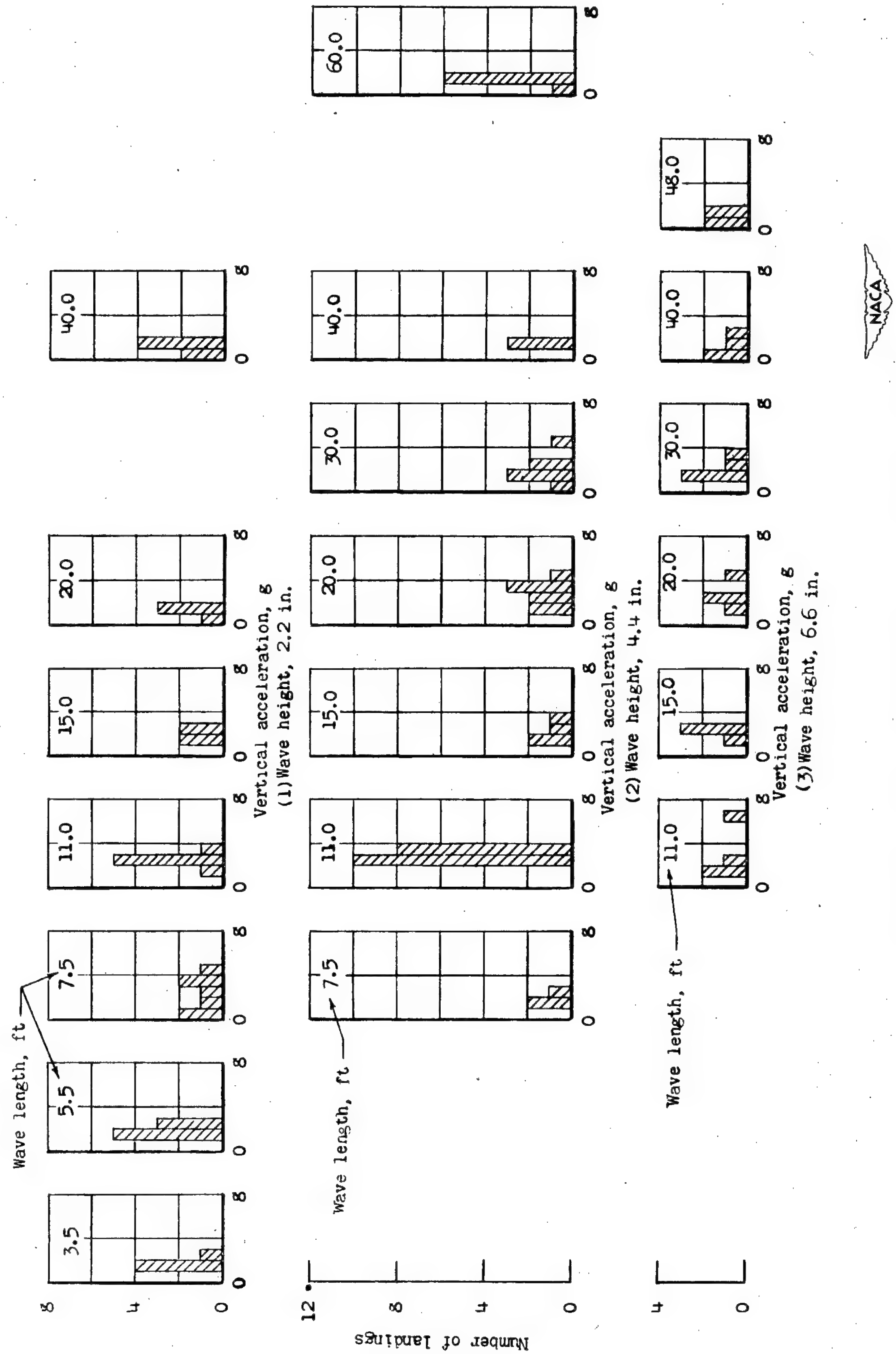
(a) Model 164L. Acceleration at initial impact.

Figure 12.- Number of landings in which the indicated initial and maximum vertical accelerations were encountered.



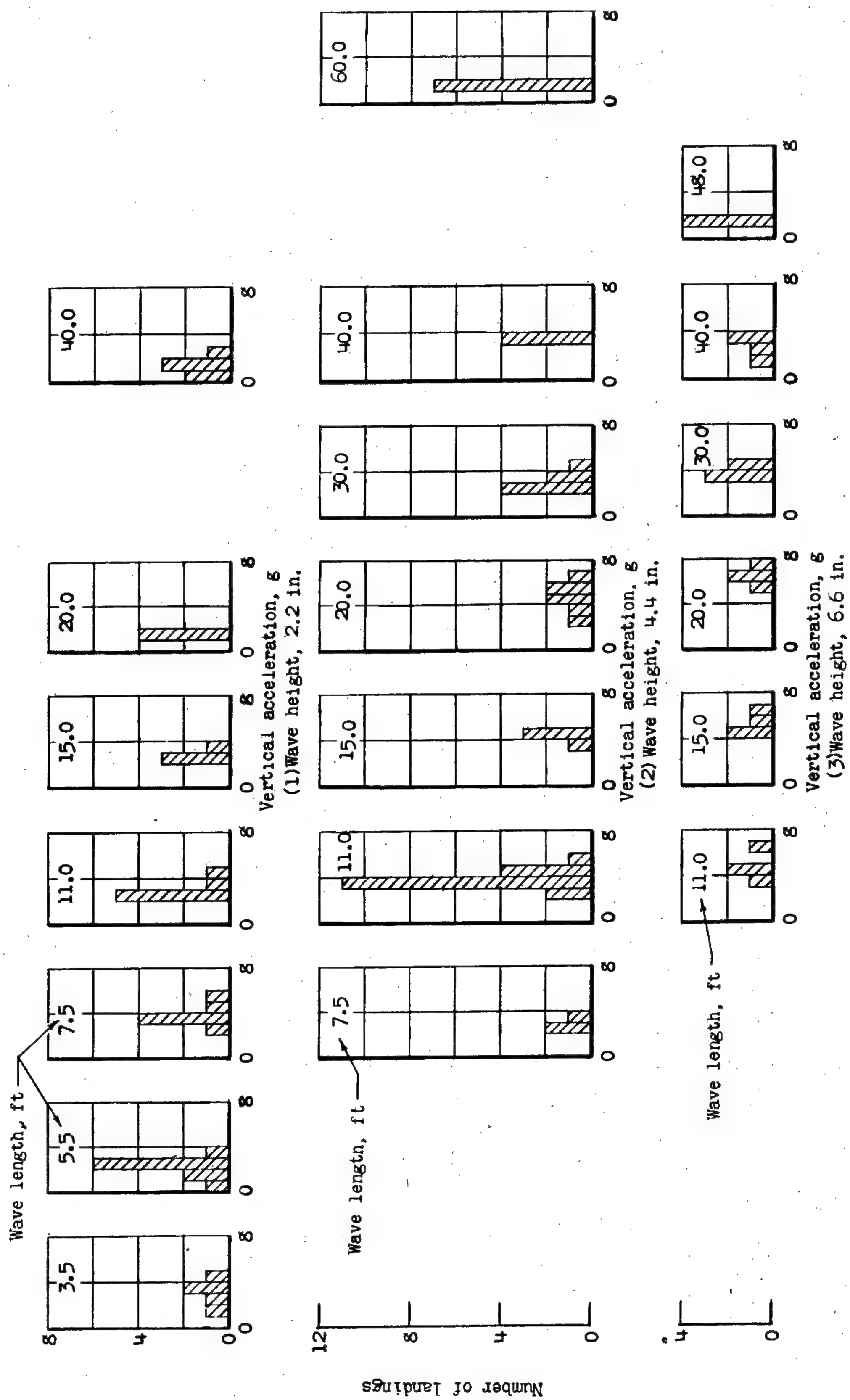
(b) Model 164L. Maximum acceleration that occurred during landing run.

Figure 12.- Continued.



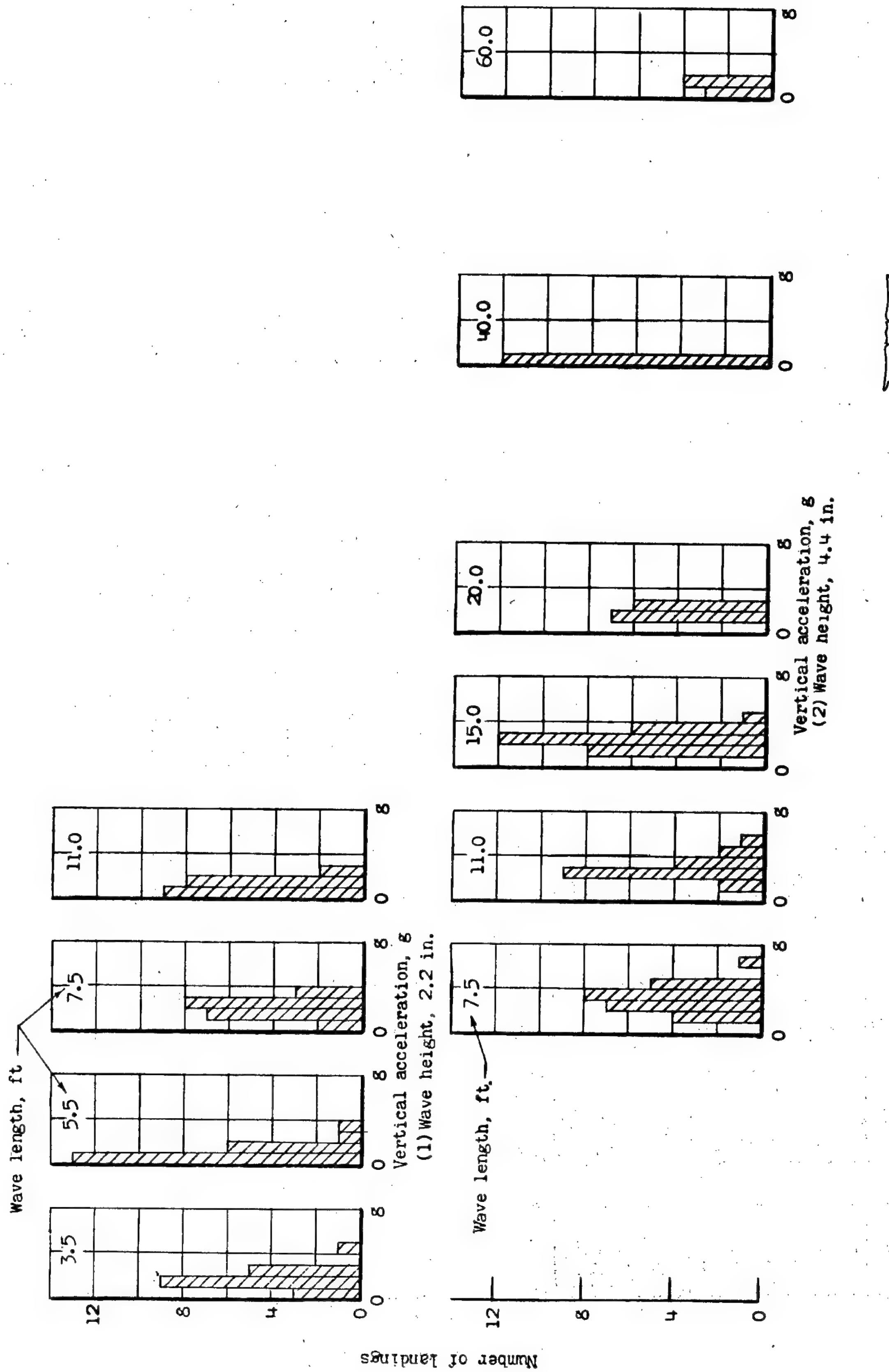
(c) Model 164J. Acceleration at initial impact.

Figure 12.- Continued.



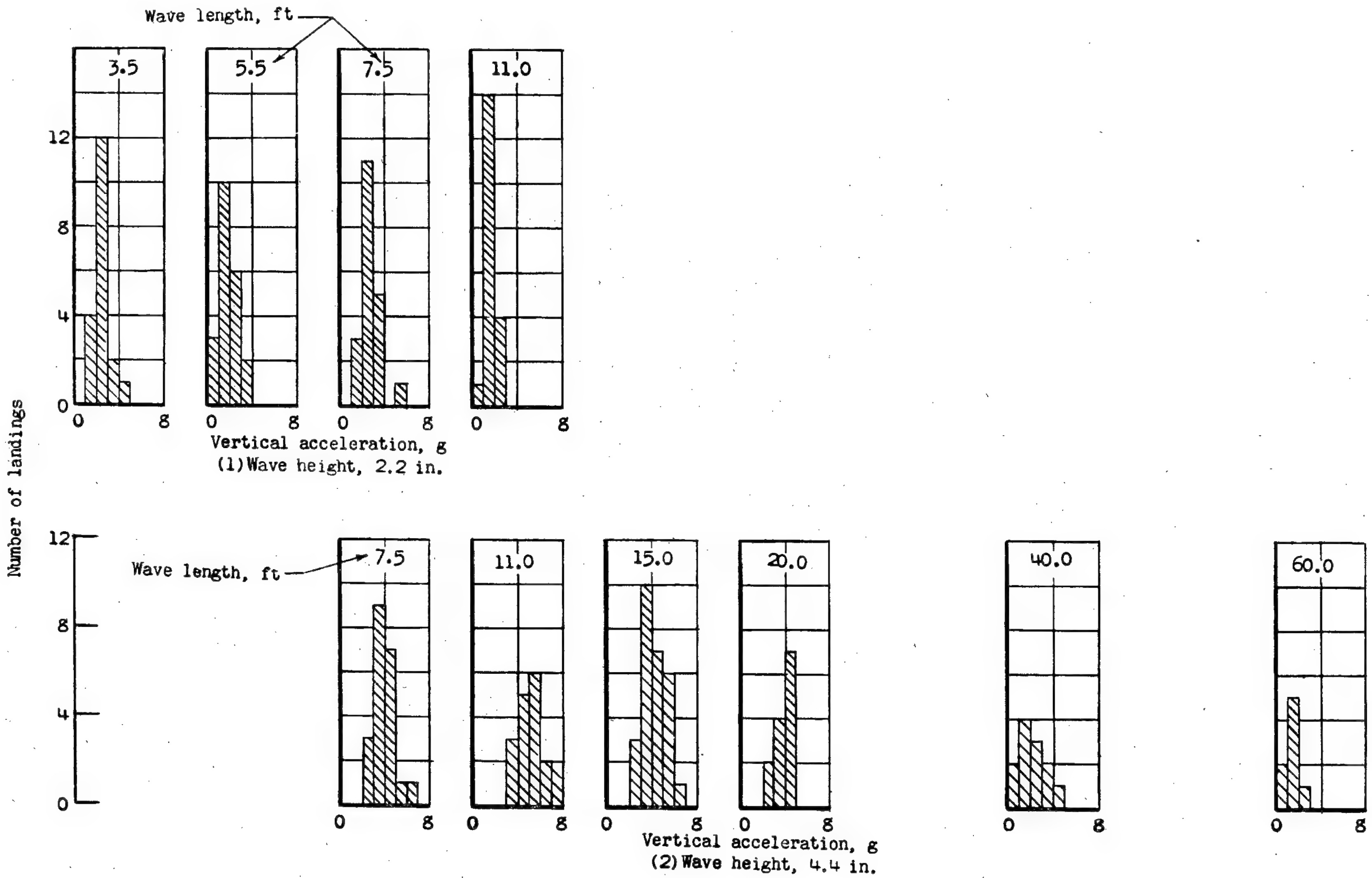
(d) Model 164J. Maximum acceleration that occurred during landing run.

Figure 12.- Continued.



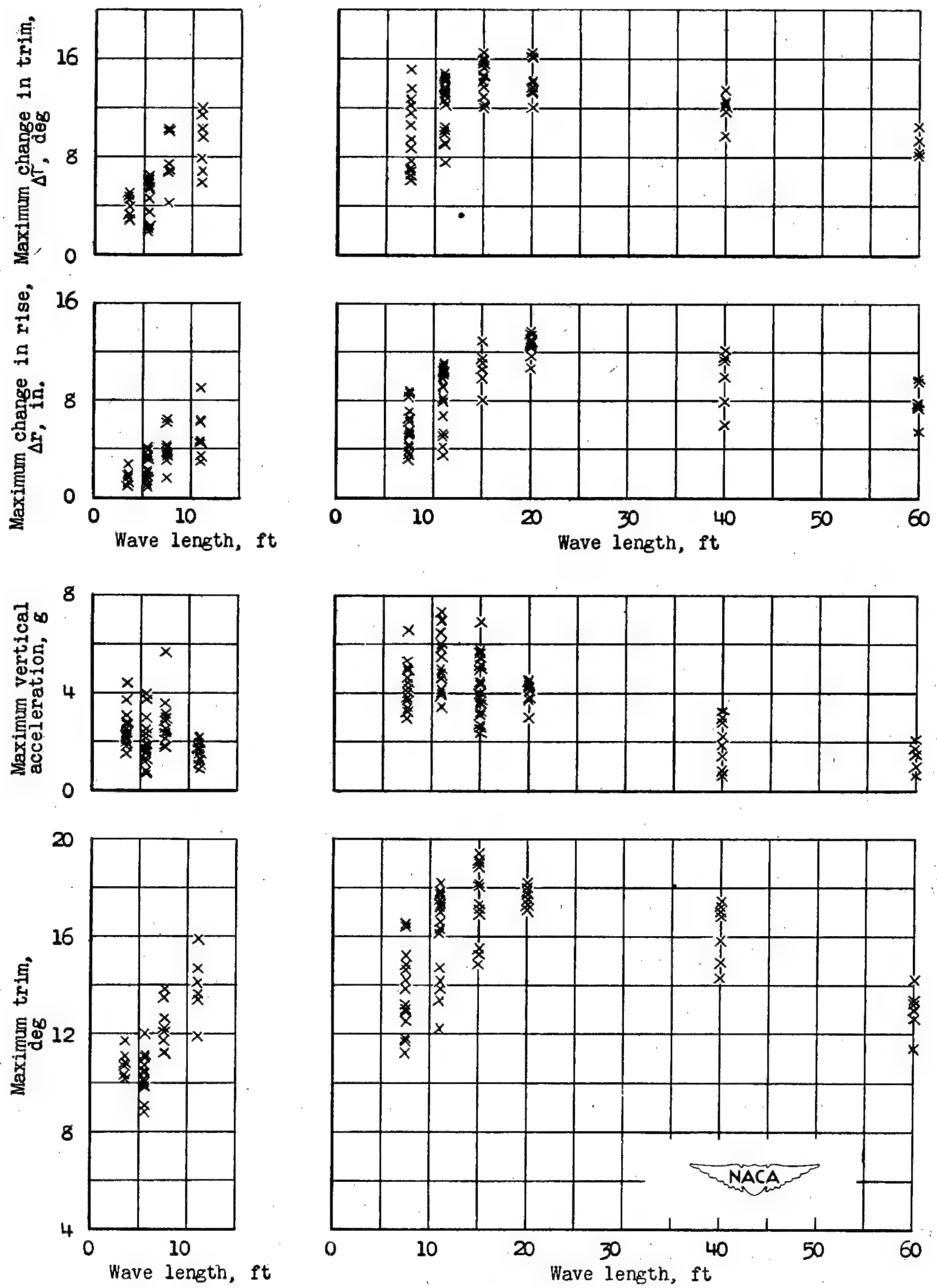
(e) Model 206. Acceleration at initial impact.

Figure 12.- Continued.



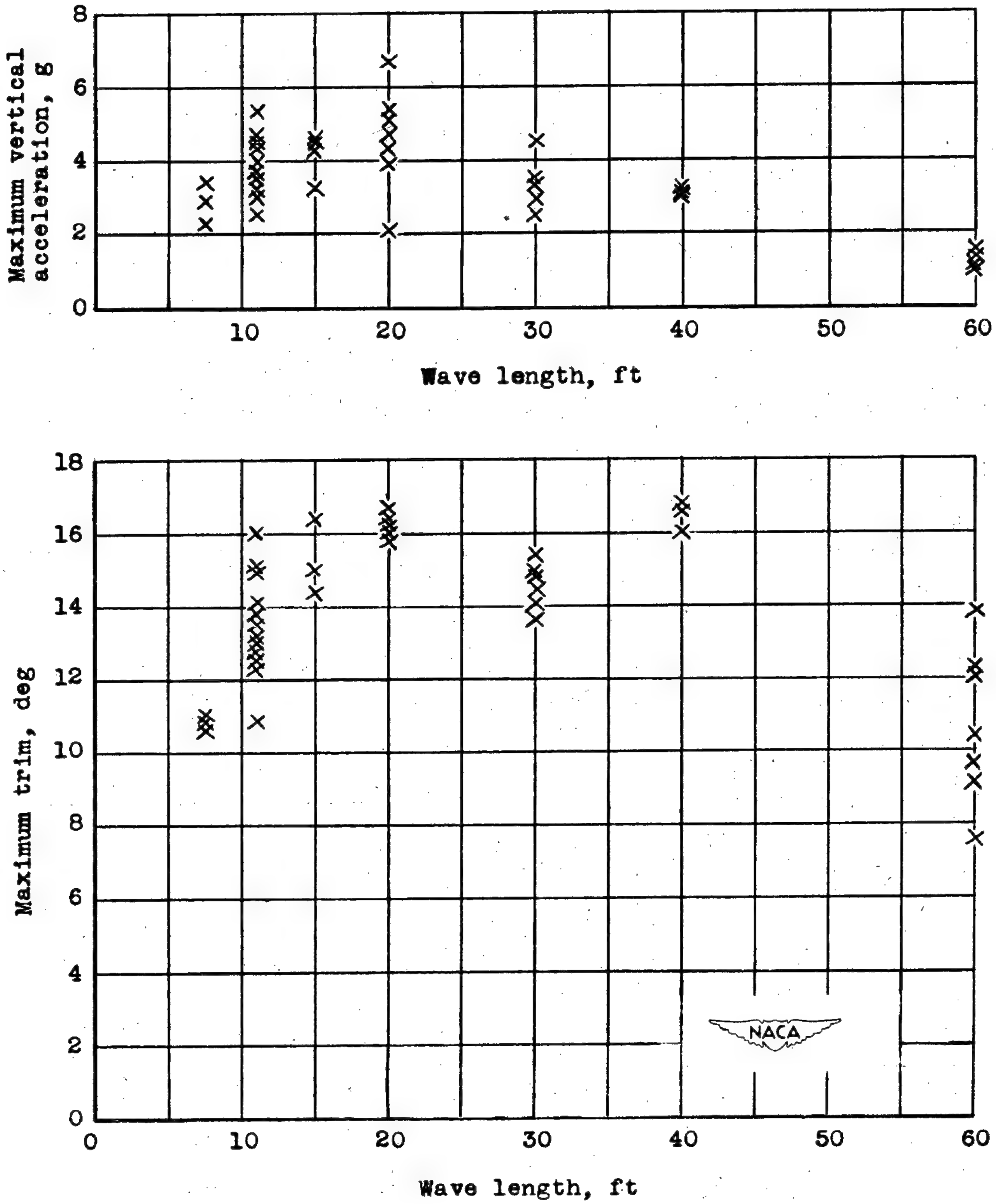
(f) Model 206. Maximum acceleration that occurred during landing run.

Figure 12.- Concluded.



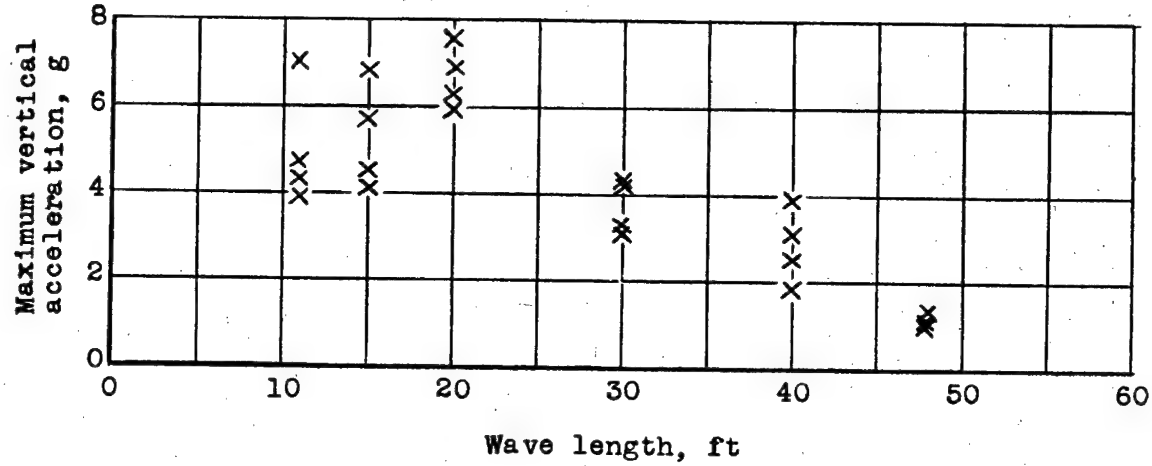
(a) Wave height, 2.2 inches. (b) Wave height, 4.4 inches.

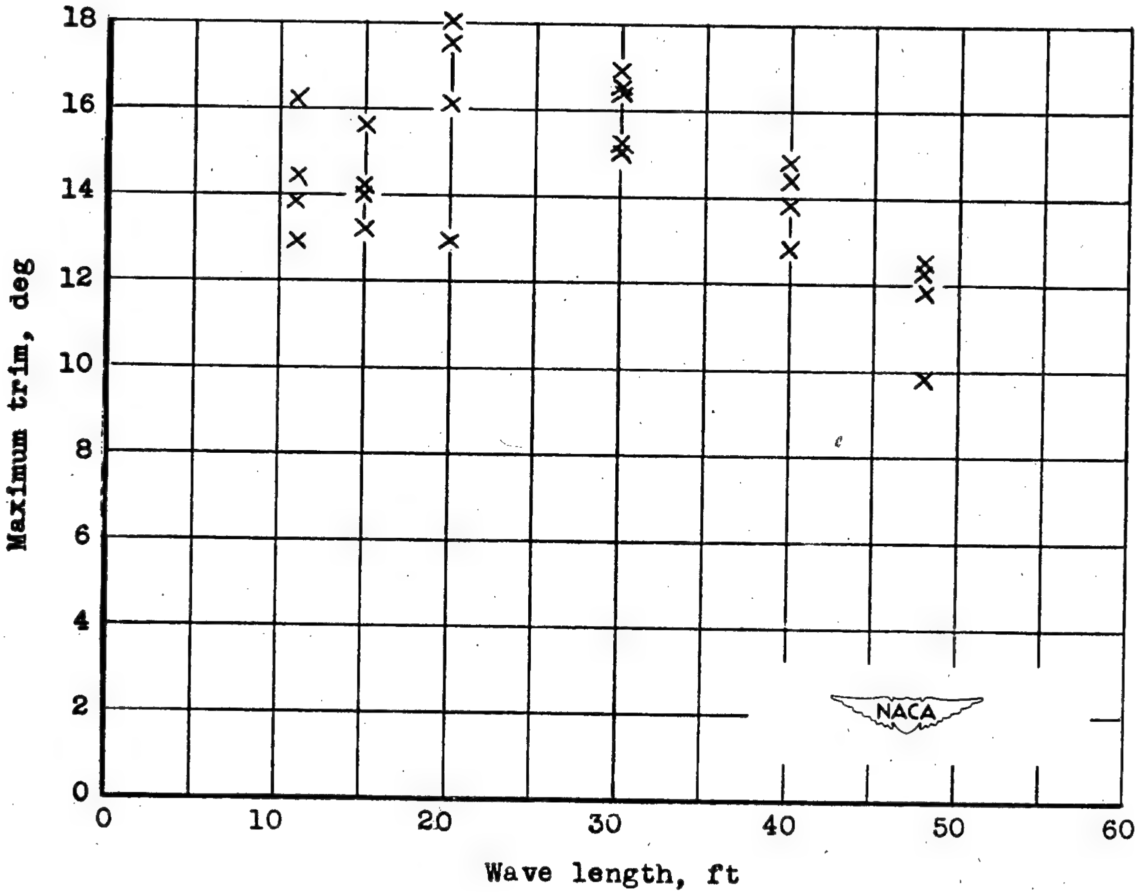
Figure 13.- Langley tank model 206. Variation of maximum trim, vertical acceleration, and change in trim and rise with wave length.



(a) Wave height, 4.4 inches (4.4 feet, full size).

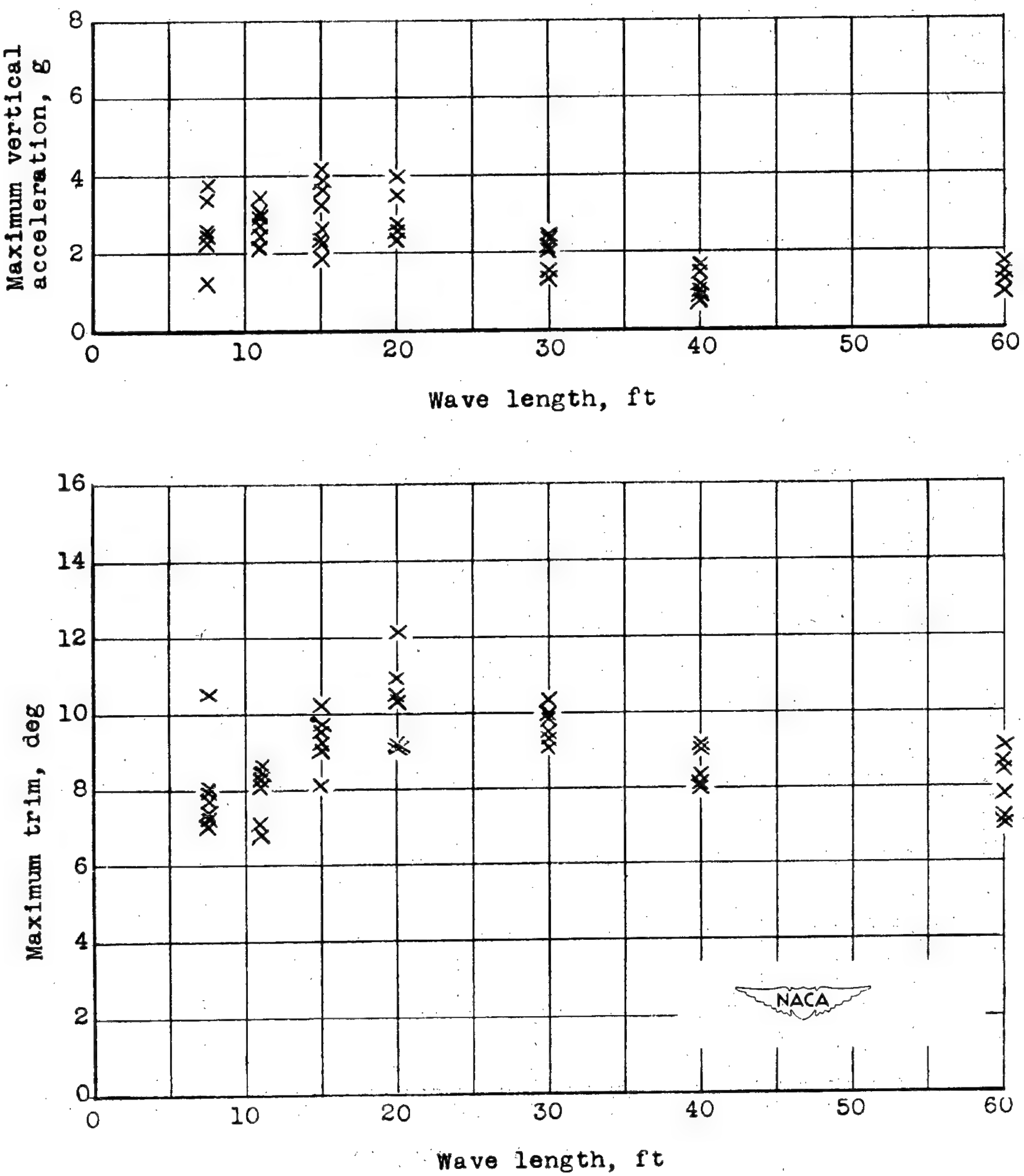
Figure 14.- Langley tank model 164J. Variation of maximum vertical acceleration and maximum trim with wave length.





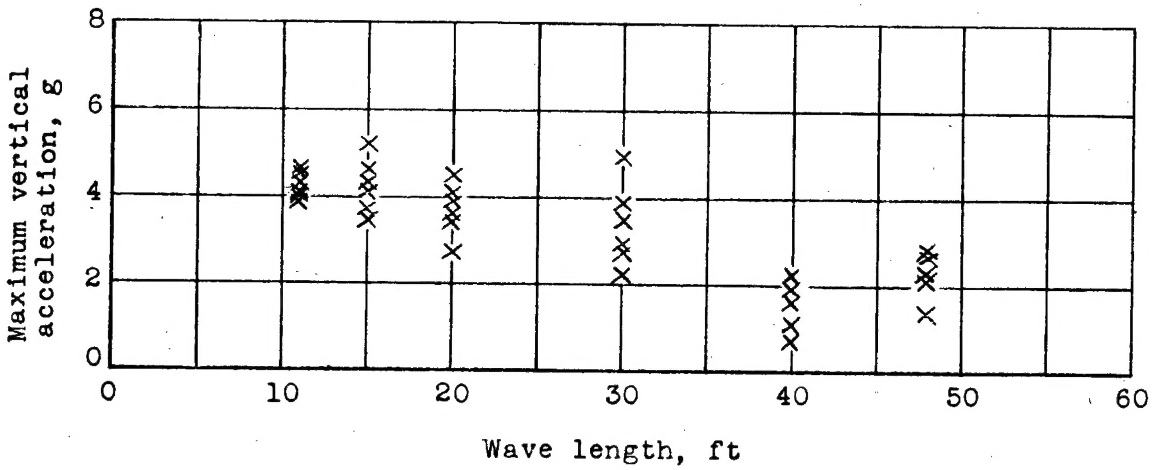
(b) Wave height, 6.6 inches (6.6 feet, full size).

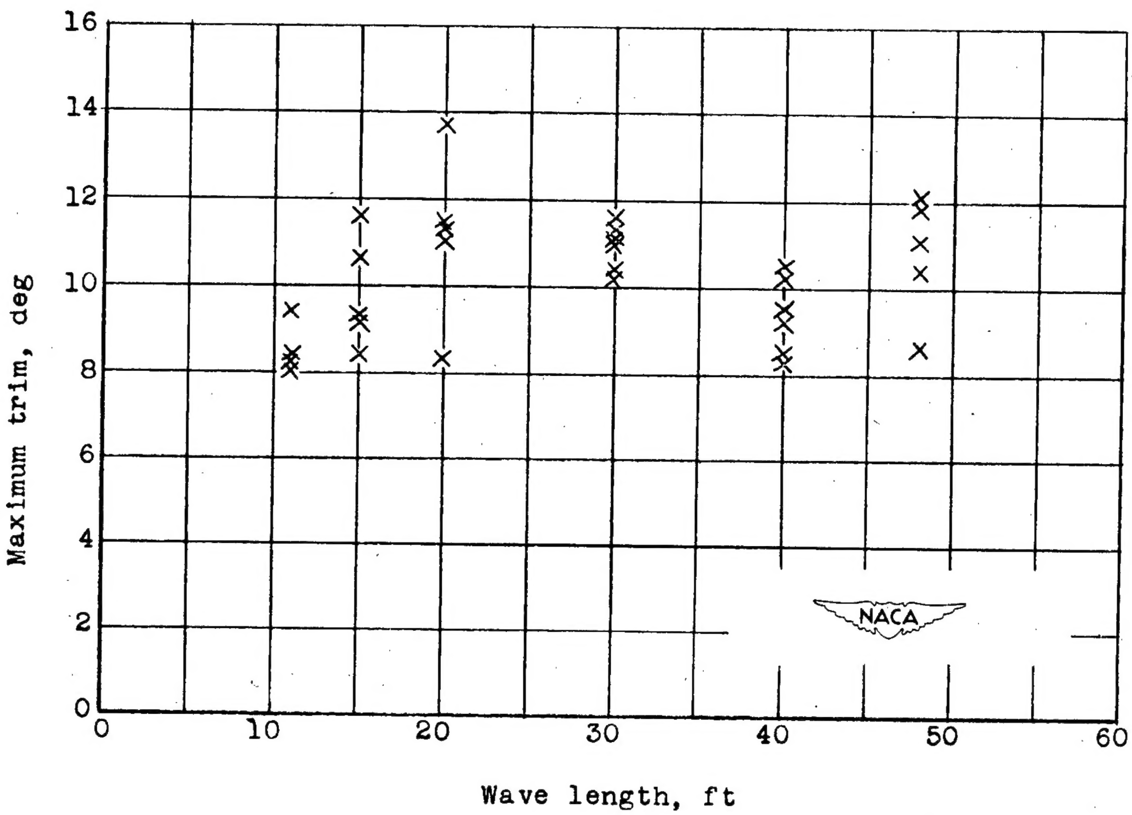
Figure 14.- Concluded.



(a) Wave height, 4.4 inches (4.4 feet, full size).

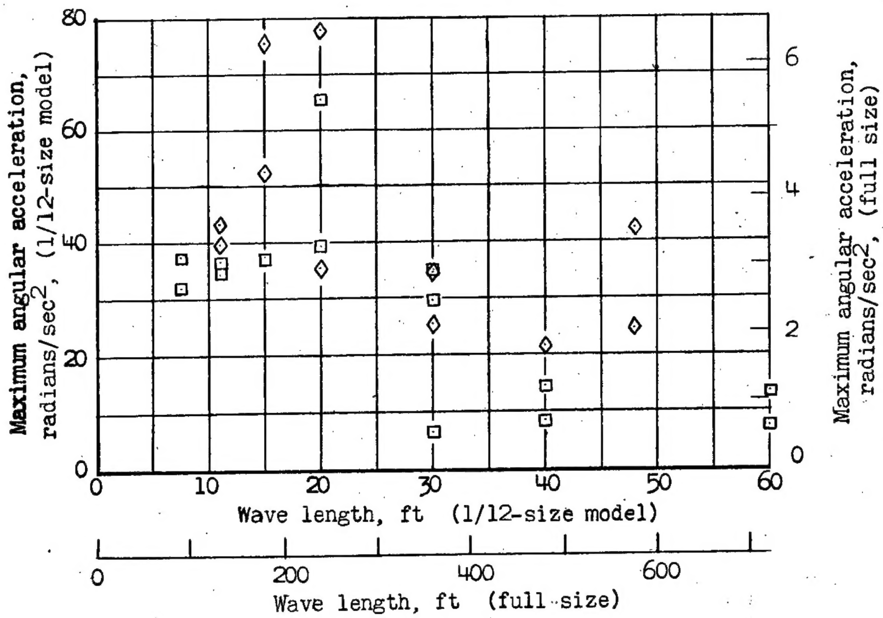
Figure 15.- Langley tank model 164L. Variation of maximum vertical acceleration and maximum trim with wave length.



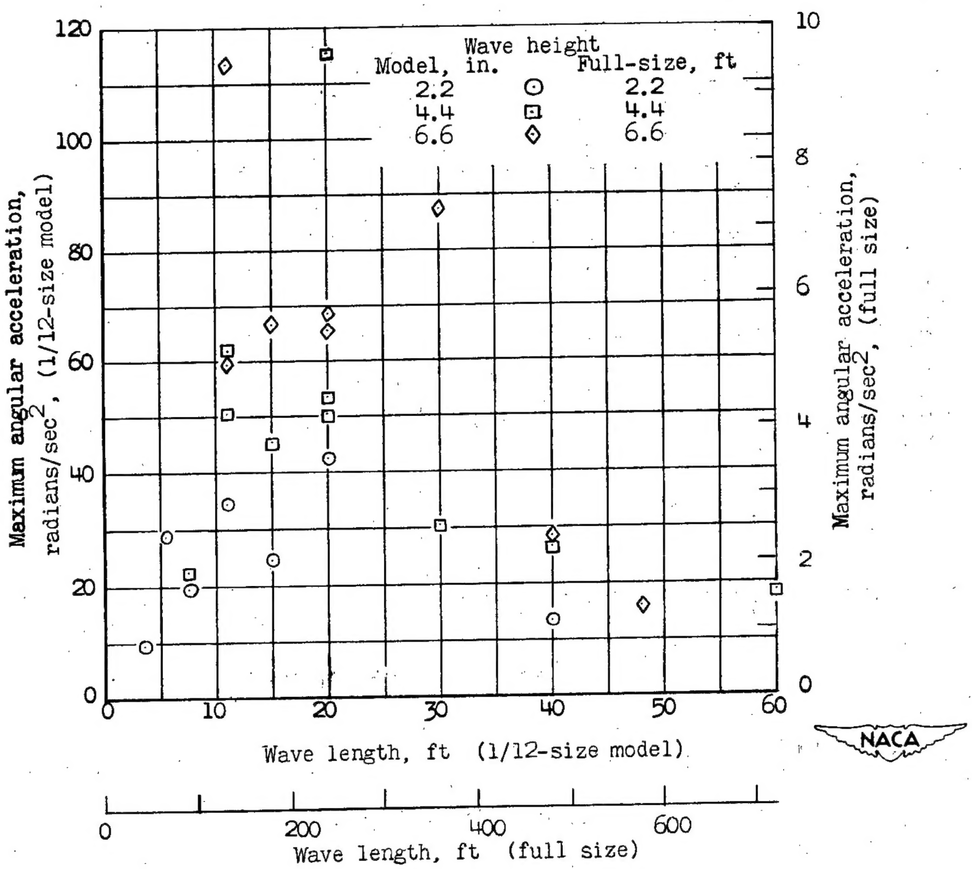


(b) Wave height, 6.6 inches (6.6 feet, full size).

Figure 15.- Concluded.

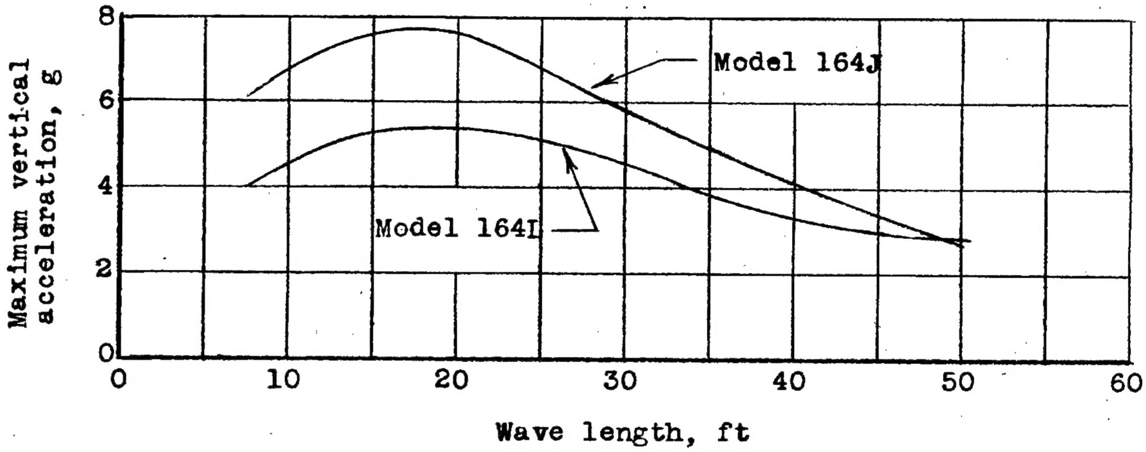


(a) Model 164L.



(b) Model 164J.

Figure 16.- Langley tank models 164J and 164L. Maximum angular accelerations calculated from records of landings in rough water.



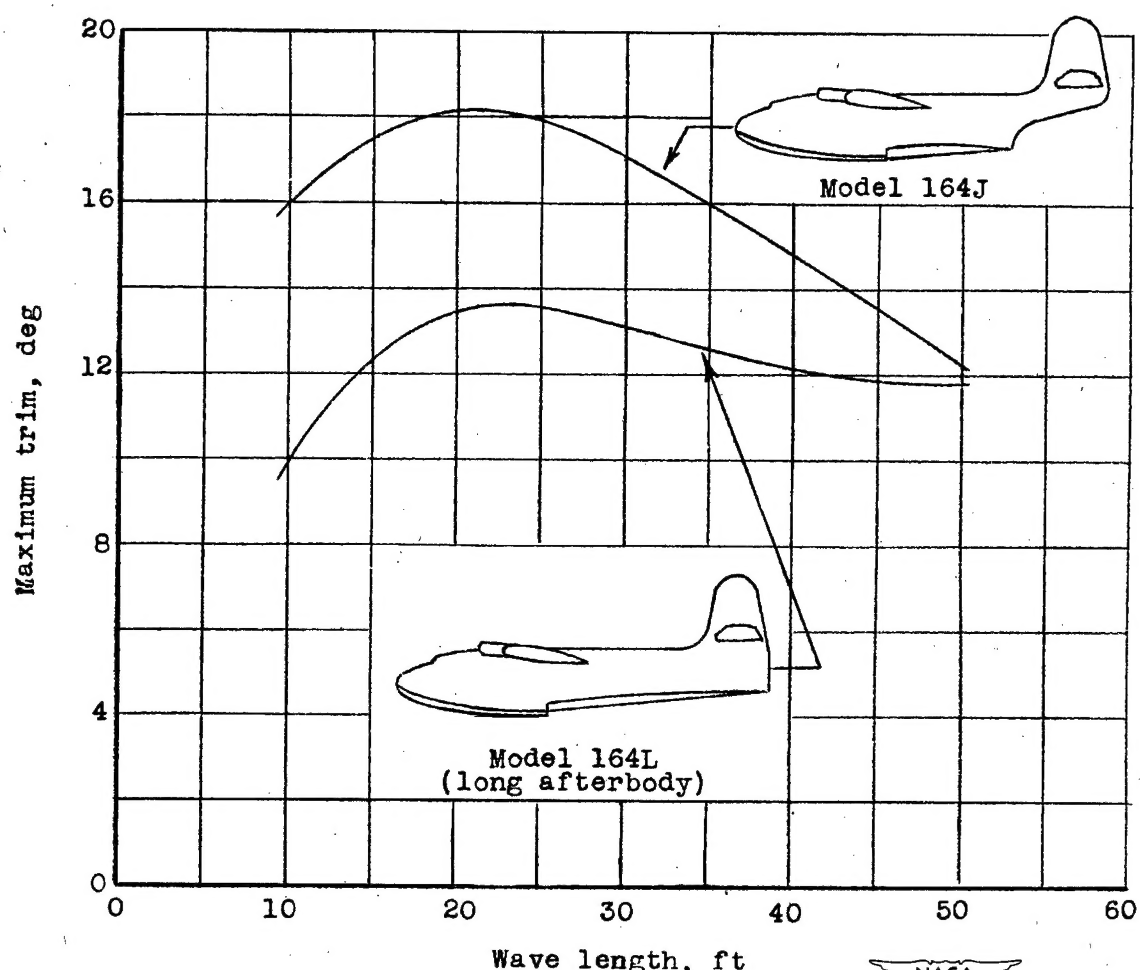


Figure 17.- Langley tank models 164J and 164L. Effect of length of afterbody on maximum vertical acceleration and maximum trim. Wave height, 6.6 inches (6.6 feet, full size).

NACA TN 2508
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LANDING CHARACTERISTICS IN WAVES OF THREE DYNAMIC MODELS OF FLYING BOATS. James M. Benson, Robert F. Havens and David R. Woodward. January 1952. 41p. diagrs., photo., 2 tabs. (NACA TN 2508. Formerly RM L6L13)

Powered models of three different flying boats were landed in oncoming waves of various heights and lengths. The effects of varying the trim at landing, the deceleration after landing, and the size of the waves were determined. Data are presented on the motions and accelerations obtained during landings in rough water.

Copies obtainable from NACA, Washington

1. Hulls, Seaplane - Afterbody Shape (2.3.4)
2. Seaplanes and Hulls - Specific Types (2.4)
3. Loads, Landing - Impact, Water (4.1.2.1.2)

I. Benson, James M.
II. Havens, Robert F.
III. Woodward, David R.
IV. NACA TN 2508
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